COMPARISON OF VITAMIN E AND NATURAL ANTIOXIDANTS ON THE LEAN COLOR AND RETAIL CASELIFE OF GROUND BEEF

By

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DEDICATION

This thesis is dedicated to my late grandfather, S. Prescott Down. His lifelong dedication to agriculture and dreams to make the world a better place for his family not only inspired me to pursue this degree, but are also a constant reminder for me to strive to be all that I can be. For it is only through hard work and dedication that goals become reachable and success is achievable. It is my dream to contribute as much to my chosen field as my grandfather contributed to agriculture and the beef industry. Somehow I think he knows.

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Format of Thesis

This thesis is presented in the Journal of Animal Science style format, as outlined by the Oklahoma State University graduate college style manual. The use of this format allows for independent chapters to be prepared suitable for submission to scientific journals.

CHAPTER I

INTRODUCTION

As we approach the new millennium, the United States beef industry will be faced with many challenges that they will be forced to continue to address. Remaining competitive in domestic and global marketplaces as well as achieving high customer satisfaction ratings will be at the top of the list for the next thousand years.

Currently, the United States beef industry is fighting a marketshare battle with the pork and poultry industries. Since 1976 the beef industry has lost more than 25% of its marketshare (USDA, 1997). If this trend continues it is expected that beef will hold only 26% of total meat marketshare by the year 2005. In order to win the fight and regain already lost marketshare, the beef industry will be forced to provide consumers with a high quality product that is enjoyable and pleasing. Pelzer (1997) and co-workers stated that per capita consumption of food has shown little change over the past 25 years and that the demand for future growth is unlikely. However, there has been a drastic shift in the percentage of products purchased by consumers. Consequently, the beef industry has seen a drastic *decrease* in the demand for its products over the past 25 years.

Not only does the consumer desire beef products that are consistently palatable, but they also *expect* that same product to appear "fresh" or bright cherry red in color.

Consumers tend to associate beef that is not bright cherry-red in color to "yesterday's meat" or meat that is unacceptable from a wholesomeness and freshness standpoint. Any deviation from this bright cherry red color leads to customer dissatisfaction and creates a "bad experience" (Kropf, 1980). Therefore, when beef begins to turn dark in color retailers are forced to either discount, further process or even discard the product. The National Cattleman's Beef Association (1993) estimated that this type of activity costs the U.S. beef cattle industry $520 million annually at the retail level (Wheeler et al., 1996). Discoloration of beef products is also a great concern internationally as well. The results of the 1994 International Beef Quality Audit stated that beef case-life was the fifth largest concern of all international beef customers as well as the largest concern of the Japanese retail sector (Sherbeck et al., 1994). By making improvements in the lean color and case-life, the beef industry should be able to grow and increase their marketshare internationally.

When beef is exposed to oxygen, myoglobin becomes oxygenated and forms oxymyoglobin. Meat in the oxymyoglobin state eventually oxidizes and forms metmyoglobin. Once approximately 70% of a myoglobin population reaches this state, meat is either discounted in price or discarded (Daun et al., 1971). At the stage in which beef darkens or discolors, retailers have three

options: 1) discount or mark the product down, 2) completely discard the product and 3) convert the product to a different product by grinding or further fabrication.

The amount, or level, of myoglobin in muscle is responsible for giving beef its color. Beef discoloration can be attributed to the introduction of oxygen to deoxymyoglobin on the muscle surface. This causes the formation of oxymyoglobin and is responsible for the change in color from purple to bright cherry red. Oxymyoglobin is then oxidized yielding the metmyoglobin state which is associated with the brown color of meat and occurs when 40 to 60% of oxymyoglobin is oxidized. Wescott et al. (1997) indicated that a brown spot as small as the size of a dime has been shown to negatively affect the purchasing decision of consumers.

By minimizing or delaying the formation of metmyoglobin; the case-life, or number of days a meat product can be displayed prior to removal from the case, can be significantly increased. Antioxidants have been shown to delay the onset of metmyoglobin formation thus increasing the case-life of meat products. The most extensively used synthetic antioxidant is α-tocopherol acetate the ester form of Vitamin E which acts to protect the cell from oxygen thus slowing the formation of metmyoglobin. Faustman and co-workers (1989) revealed that by feeding 370 IU/hd/day for 300 d improved lean color scores and reduced the formation of metmyoglobin when compared to meat from non Vitamin E supplemented animals. A concentration of 3.0 μg/g of vitamin E in muscle tissue has been proven to increase the case-life of retail beef products (Schaefer et al.,

1995; Smith et al., 1996). This can be accomplished by supplementing feedlot cattle with 500 to 1,000 IU/hd/day for 100 days prior to harvest.

More recently, research has been done to determine the effect of adding natural antioxidants such as ascorbic acid and extracts of rosemary to meat products in order to simulate the same results as Vitamin E. Cuvelier et. al. (1995) suggested that extracts from rosemary and sage plants show strong antioxidant characteristics in certain foods. Wada and Fang (1992) reported that combinations of these two extracts with Vitamin E were synergistic; therefore, improving antioxidant activity in certain foods.

Improving the quality and image of beef and beef products is the first step towards winning the marketshare battle with the pork and poultry industries. This can be accomplished by extending the amount of time beef products can remain in the retail case without developing an undesirable color. If natural antioxidants can be used to prolong the case-life of beef products, it is possible that millions of dollars could be spared annually in the U.S. alone. The objective of this study is to determine if natural antioxidants, synthetic antioxidants and antioxidant combinations can be used to increase the amount of time beef products can be displayed prior to being discarded or discounted.

CHAPTER II

LITERATURE REVIEW

Consumer Perceptions

Numerous studies have shown that consumers take several factors into consideration when purchasing fresh beef. Beef quality, source of origin, and nutrient content are a few of the factors considered by consumers when purchasing beef. However, fresh meat color is one of the first factors that consumers consider when selecting and purchasing raw beef (Green et al., 1971). Lean color is very important to the appearance of beef products and influences consumer perception in the retail case (Sherbeck et al., 1995). The consumer associates bright cherry red color with freshness and considers that product to be one of "quality" (Faustman and Cassens, 1990). In fact, if the consumer does not perceive beef color to be bright cherry red they often consider the product to be unacceptable or even rancid (Kropf, 1980). Research conducted by Trinkaus (1995) revealed that uncooked ground beef can be classified into three categories: 1) bright cherry red on both the outside and inside, 2) bright cherry red on the outside and brown on the inside, and 3) brown on both the outside and inside. Trinkaus (1995) further stated that consumers consider the first category to be today's meat, the second to be yesterday's meat covered with a layer of today's meat and the third category to be yesterday's

meat. This explains why the retailer generally discounts or discards beef products that are not bright cherry red in color.

Unfortunately, meat deteriorates due to chemical and microbial processes immediately following harvesting. Meat begins to oxidize about 30 minutes after being exposed to oxygen and continues to oxidize for approximately 3 days. Much of the meat that is eaten contains biomolecules that are attacked by free radicals during oxidation (Shahidi, 1996). This occurs due to oxidative processes that affect meat and meat products resulting in discoloration and rancidity in fresh meat and the warmed over flavor in processed meats (Wong et al., 1995). Several ways to prevent or slow this oxidative process are: curing, vacuum packaging and the use of both natural and synthetic antioxidants. However, free radical oxidation of meat products is a major concern of consumers as well as food manufacturers.

Currently, the beef industry has the opportunity to decrease or even eliminate the number of inferior visual experiences concerning its products by improving the color of its products at the retail or consumer level. Since the consumer links lean color with freshness, it is imperative for the beef industry to provide its customers with a "quality" product that meets their expectations from a color standpoint with every purchase. In 1993, The National Cattleman's Beef Association stated that beef discoloration alone costs the U.S. beef industry approximately $250 billion annually (Wheeler et al., 1993). Williams and others (1992) estimated that an increase in shelf-life of 1-2 days could potentially save the beef industry between $175 million and $1 billion annually.

It has also been estimated that the American consumer has more than 10,000 shelf-stable products to choose from at the retail level. This number has drastically increased in recent years partially due to the fact that these products have an increased shelf life compared to products available in the past. Even perishable products are able to remain edible for longer time periods due to antioxidants and preservatives. The increasing popularity of natural antioxidants has played a large role in increasing the shelf life of many meat based food items (Brookman, 1991; Dorko, 1994).

In recent years, the consumer has demanded food products that are labeled "natural." The United States food industry alone witnessed a 175% increase in "all-natural" products between 1989 and 1990. There was also a 99% increase in the number of "additive-free" products during that same time period. In order to remain competitive and maintain marketshare, it has become necessary for food processors to respond to consumer demands. This has caused an increase in the demand for natural antioxidant research and use.

The use of natural antioxidants may be helpful in not only prolonging display time of processed meats products, but they are also viewed as a natural alternative to other additives and preservatives currently used in the meat industry.

Lipid Oxidation: Its Affect on Meat Quality Deterioration

One of the major causes of meat quality deterioration is lipid oxidation and the biochemical changes associated with it. Lipids can be classified in the

following two categories: 1) depot lipids and 2) tissue lipids (Love et. al., 1971). Depot lipids are those generally stored in large quantities such as connective tissue (Pearson, 1986). Tissue lipids, on the other hand, are usually found in small quantities in lean tissue (Pearson, 1986). Pearson and co-workers (1977) also determined that lipids play an important role in species flavor of meat, but are also very subjective to lipid oxidation. These qualities allow lipids to give beef a desirable or undesirable flavor. Furthermore, lipid oxidation can be broken down into two categories: oxidation that occurs during storage and oxidation that rapidly occurs following the cooking process (Pearson, 1986).

Lipid oxidation, the combination of organic compounds and atmospheric oxygen, produces a free radical chain of events that adversely affect muscle pigment and lipid stability (Kanner, 1994; Gordon, 1990). Rhee and others (1988) determined that iron is a major catalyst in the lipid oxidation process. Furthermore, the amount of iron found in tissue has been reported to change drastically postmortem (Decker and Welch, 1990). Several researchers have reported a drastic increase in lipid oxidation when a ferritin-bound iron is added to muscle tissue. Seman et al., (1991) reported that the addition of ferritin-bound iron caused an increase in lipid oxidation.

When lipid is initially oxidized, primary and secondary products result. These products eventually affect the visual properties of meat and ultimately cause it to be undesirable. Lipid oxidation begins when unsaturated fatty acids react with molecular oxygen causing the formation of acyl hydroperoxides, commonly known as peroxides. A hydrogen atom is removed from a fatty acyl

chain, which produces a free lipid radical. This free lipid radical reacts very quickly with oxygen and subsequently forms a peroxyradical. This causes a chain reaction resulting in each peroxyradical scavenging a hydrogen atom from another hydrocarbon chain which leaves a new peroxyradical to continue the chain reaction. As this reaction continues and eventually resulting in the rancidity of meat products. Roberfroid and Calderon (1995) defined a free radical as "any chemical species that has an odd number of electrons, because it contains one or more unpaired electrons, that is, an electron that occupies an atomic or molecular orbital by itself." Free radicals are capable of existing independently as opposed to bound radicals. They also stated that free radicals are generally chain reactions that occur in three steps (Roberfroid and Calderon, 1995). They are initiated, propagated and eventually terminated.

Rikans and Hornbrook (1997) proposed the idea that human aging can be contributed to the addition of irreversible damage from attack by free radicals on cellular structures. They also hypothesized that aging is caused by a shift in pro-oxidant and antioxidant levels favoring the pro-oxidative state. Rikans and Hornbrook also stated that the free radicals associated with the aging process are derived from oxygen either directly or indirectly. This compliments the theory that oxygen radicals cause and/or initiate lipid peroxidation.

Certain metals have been proven to increase or speed the lipid oxidation process by aiding in the transfer of electrons which increases the number of free radicals (Ingold, 1962). Several studies have also shown that any processing procedure that disrupts the muscle membrane may also speed the lipid oxidation

process. When meat is cooked, deboned, ground, etc.; lipid constituents become further exposed to oxygen thus speeding the oxidation process (Sato and Hagerty, 1971).

According to Labuza (1971), substances that show antioxidant activity can be classified in the following categories:

1. *Free Radical Terminators*. These substances donate an electron to the free radical and stop the chain reaction.
2. *Free Radical Preventors*. Control the production of free radicals.
3. *Environmental Factors*. Natural antioxidants.

Meat Color Deterioration

One of the major problems associated with the sale of fresh meat is the occurrence of a dark brown color (i.e., metmyoglobin) on the exterior portion of the product (Green, 1969). Hutchins et al., reported that there is a strong (.73) correlation between metmyoglobin formation and lipid oxidation. It has not yet been determined if oxidizing lipids cause muscle pigments to discolor or if pigment discoloration initiates lipid oxidation. However, Greene (1969) used the lipid antioxidants propyl gallate and butylated hydroxyanisole to discourage lipid oxidation. She determined that the treated meat products kept their lean color longer and rancid odors were retarded. Greene (1971) attempted to prolong beef shelf life by using a combination of lipid antioxidants to reduce metmyoglobin formation and reduce lipid oxidation rates. Less pigment loss was found in the raw meat samples treated with a combination of antioxidant products. It was also concluded that there was no direct relationship between pigment concentration and the rate of overall discoloration. Color scores of 4 on a scale of 1 to 8 with 1

being extremely undesirable and 8 being extremely desirable, had more than 45% metmyoglobin formation indicating that the amount of ferric pigments determines color acceptability, not overall pigment concentration.

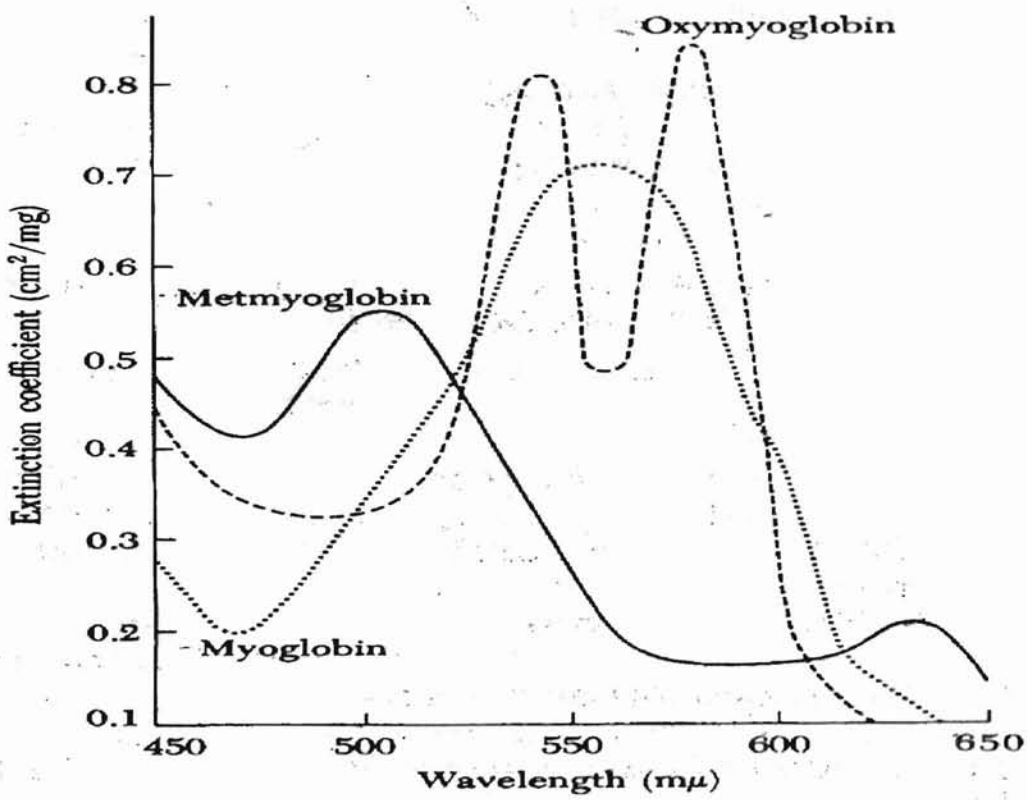


Figure 1.1: The absorption spectra of the three most common forms of myoglobin in fresh muscle tissue (Price and Schweigert, 1987)

When considering fresh meat color, there are two main pigments that determine how bright or dark red the product appears to be (Figure 1.1). These two pigments, hemoglobin (Hb) and myoglobin (Mb), are located in the blood and tissue, respectively. Hemoglobin is a fairly large molecule that is dark purple in color as it is observed in the blood. However, when it is exposed to oxygen it

turns bright red. Myoglobin on the other hand, is a much smaller molecule that is also found in muscle tissue. When myoglobin is observed in living tissue or immediately after exposure to air, it remains purple in color. When muscle tissue is in these two stages, iron is in the ferrous form (Fe^{2+}) and myoglobin is considered to be in the deoxymyoglobin state. However, once the muscle surface is exposed to air, deoxymyoglobin becomes "oxygenated" and is converted to the oxymyoglobin state. At this point, the muscle surface is bright cherry red in color and the iron molecule is still in the ferrous (Fe^{2+}) state. The time it takes deoxymyoglobin to be transformed into oxymyoglobin is known as "bloom time." The final color transformation occurs when oxymyoglobin is transformed into metmyoglobin. This process involves the loss of one electron from the iron molecule yielding the ferric state (Fe^{3+}) as well as the removal of O_2 from oxymyoglobin. Once O_2 is removed from oxymyoglobin, a hydrogen peroxide molecule binds in its place. Little is known about the rate of beef discoloration. However, the metmyoglobin state is often associated with a very dark brown or even green color which ultimately results in the discarding of beef products at the retail level.

Another factor that affects beef color stability is oxygen consumption rate (OCR). This is accomplished by altering the depth of metmyoglobin formation. When meat has a high OCR, or consumes O_2 rapidly on the muscle surface, oxygen fails to penetrate deep into the product causing the metmyoglobin layer to form just beneath the surface, and therefore the meat discolors rapidly (Madhavi and Carpenter, 1993). The point where oxygen penetrates the meat

surface the deepest is referred to as the Met-line which is very important in determining the rate of beef discoloration (M-TEK, 1997). When the pO_2 increases, the Met-Line becomes further from the meat surface. When the pressure of oxygen begins to decrease, the Met-Line starts to form and subsequently causes the initiation of metmyoglobin formation (Schuler, 1990). At this point metmyoglobin begins to extend from the interior portion of the product towards the outer surface. This theory has lead to the idea of high oxygen case-ready packaging systems in order to achieve maximum oxygen penetration causing a deeper met-line and resulting in increased case-life. Oxygen consumption rate has been identified as the single most important factor affecting meat color (O'Keefe and Hood, 1982). Ledward (1985), on the other hand, indicated that meat discoloration is caused by the combined effect of oxygen consumption rate and pigment oxidation. Brooks (1929) reported that metmyoglobin forms beneath the surface of meat due to the lower partial pressure compared to the surface partial pressure. Research done by George and others (1952) showed that subjecting meat to oxygen concentrations higher than air had no effect on myoglobin oxidation. In contrast, Fellers (1963) and Baush (1966) both reported that oxygen concentrations higher than air showed significant improvement to fresh meat color retention. Similarly, Daun and co-workers (1971) reported that storing meat in an oxygen enriched environment allows fresh meat to remain acceptable for longer time periods than product exposed to a normal atmosphere (Figure 1.2).

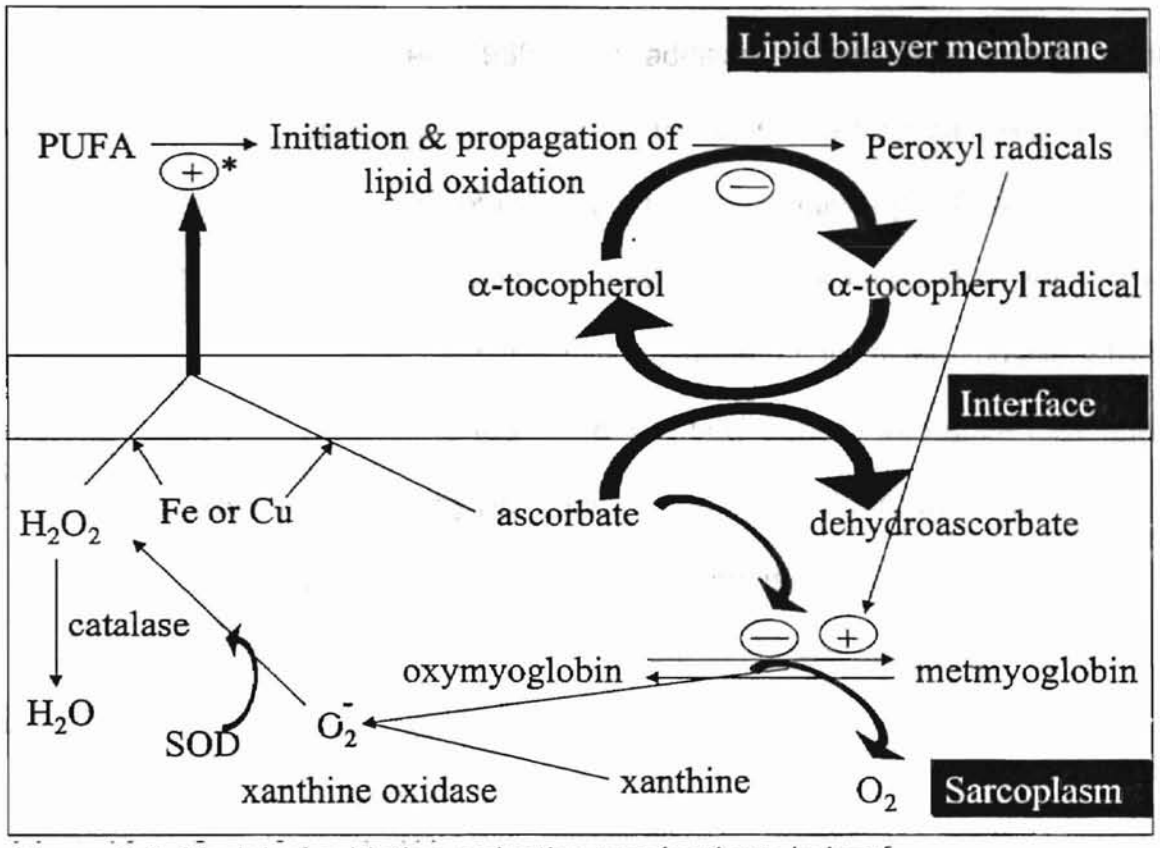


Figure 1.2: Model of oxidation-reduction mechanisms in beef.

Retail Case-life

Retail case-life can be described as the amount of time that a product can remain in the retail case and maintain an acceptable appearance as evaluated by the consumer. The average time period that most consumer panels rate ground beef products as being acceptable is approximately 2 days. Hood and Riordan (1973) discovered that at a once a meat product reached a 20% metmyoglobin level, the consumer purchased bright cherry red beef at a ratio of 2:1, or twice as often, compared to the slightly discolored product.

There are several factors that affect beef retail case-life. Temperature, light intensity, pH, packaging systems and bacterial activity are a few of those factors (Kropf, 1980; Walker, 1980). In addition, it has been proven that differences in retail case-life occur in certain muscles of a beef carcass. This is partially due to the amount of metmyoglobin reducing activity (MRA) found in the muscle. MRA causes the myoglobin to remain in its reduced state for longer periods of time which allows greater oxygen penetration in the muscle which subsequently allows the muscle to remain in a bright cherry red state for longer time periods. Research done by Hunt and Hendrick (1977) showed that muscles of differing types have different aerobic potentials. According to aerobic potential, they compared the following muscle types which are listed in descending order: psoas major > semitendinosus > longisimus dorsi > gluteus medius > semimembranosus.

Temperature

Hood (1980) found that the major cause of beef discoloration is due to muscle type. He also noted that muscle temperature accounted for 35% of the total variation in beef discoloration. As temperature increases so does the formation of metmyoglobin. This can be explained by work done by Kanner (1994) and Walters (1974) in that it appears that high temperatures cause myoglobin to be cleaved and oxygen to be released. This causes the formation of hydrogen peroxide and metmyoglobin formation easily occurs. The rate of photooxidation, or discoloration, is dependent on the intensity and wavelength of

light (Hood, 1980). Hood also concluded that storing beef products at 0, 5, and 10°C showed significant rates of discoloration associated with increasing temperatures.

Lighting Affects

The rate of beef discoloration is greatly affected by differing light wavelengths (Hood, 1980). When beef is exposed to light photooxidation speeds up the transformation of oxymyoglobin to metmyoglobin. Beef extract solution exposed to several light wavelengths exhibited different oxymyoglobin to metmyoglobin conversion rates (Bertlsen and Skebsted, 1987). Liquid extracts from beef semitendinosus muscle was irradiated with a monochromic light prior to OMb to MMb conversion rates being calculated. They discovered that UV light with a wavelength of 245 nm was 4,000 times more harmful than visible light. This supports the findings of Hood, 1980; and Anderson, 1988, who discovered that the rate of photooxidation of meat products is directly dependent on the wavelength of light that they are exposed to.

Packaging Affects

Many new packaging systems have been introduced to the retail counter in recent years. While case-ready packaging systems are becoming more popular, the majority of beef is still packaged using oxygen permeable film. According to Kropf (1980), this type of packaging greatly increases the rate of metmyoglobin formation. O'Keefe and Hood (1982) have done much research in

this area and determined that products stored anaerobically have a much faster rate of discoloration compared to products stored using oxygen permeable film.

pH

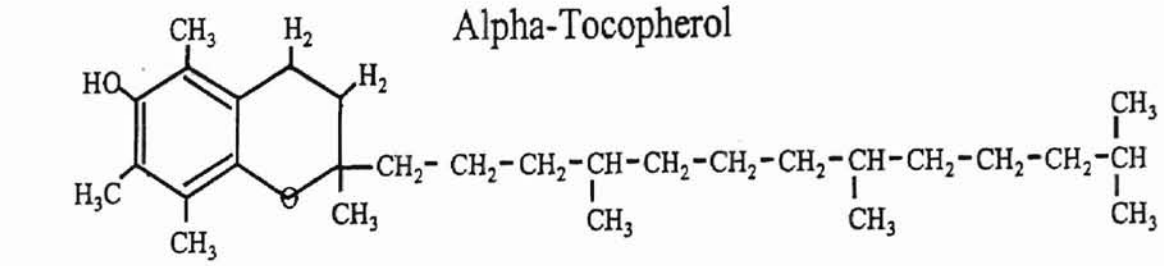
Fresh meat pH is a very important factor in determining the rate at which oxidation occurs. The normal pH range for fresh meat is 5.4 to 5.8 and oxidation usually occurs at a pH of less than 5.2. Metmyoglobin rapidly accumulates at low pH levels due to the denaturation of myoglobin molecules caused by acidic conditions. In 1954, George and Stratman concluded that at low pH levels metmyoglobin accumulation was accelerated in minced beef product. However, Hood (1980) determined that pH had no effect on meat color. Another study conducted by Anderson (1990) and co-workers found that hot deboned beef had better color and oxidative stability when compared to their cold deboned counterparts.

Bacteria

Exposing red meat to oxygen can increase the bacterial growth which ultimately results in discoloration. This occurs due to the production of hydrogen sulfide and hydrogen peroxide by some bacteria following oxygen utilization (Morgan et. al., 1993). Hydrogen peroxide and hydrogen sulfide are then attracted to the free binding site on oxymyoglobin which results in the formation of choleglobin and sulfmyoglobin which are in the Fe^{3+} form.

Vitamin E as an Antioxidant

The α-tocopherol form of vitamin E (Figure 1.3) prolongs beef shelf-life by binding to or scavenging free radicals in order to prevent lipid peroxidation during the free radical chain of reactions (McCay and King, 1980). This is accomplished by α-tocopherol donating a hydrogen atom that binds with the unpaired electron of the free radical initiator (McCay and King, 1980).



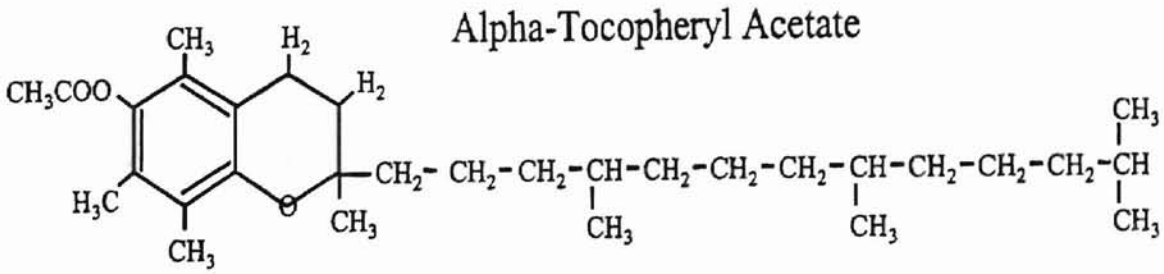


Figure 1.3: Structure of α-tocopherol and α-tocopheryl acetate (McDowell, 1989)

Several researchers have attempted to maintain beef color and lipid stability by feeding elevated levels of vitamin E for 30-100 days prior to slaughter

(Faustman et. al., 1989; Arnold et al., 1993; Garber, 1992). Feeding 2000-3000 IU of vitamin E per head per day for at least 100 days has shown to elevate tissue levels of α-tocopherol and in turn stabilizing tissues as a result of delaying lipid oxidation. Faustman (1989a) determined that the critical level of alpha-tocopherol at the tissue level needed to extend beef shelf-life is 3.0-3.7 μg/g of muscle. In a similar study, Faustman and co-workers (1989b) found that α-tocopherol concentrations of less that 3.0 μg decreased beef shelf-life due to increased metmyoglobin formation and lipid oxidation.

Further research has shown that feeding 500 IU of alpha-tocophenyl acetate per day for 123 days prior to slaughter improved beef color and increased shelf-life (Morgan et al., 1993). In the control product, 18.1%, 14.6% and 17.9% respectively of all T-bone steaks, roundtip steaks and ground chuck shoulder were discounted in price compared to only 3.1%, 5.2% and 2.2% of the same respective cuts from cattle supplemented with vitamin E. Pinkerton (1993) discovered that feeding 370 IU of vitamin E for 309 d prior to harvest improved beef color after 7 d of retail display when compared to displayed cuts from non-supplemented cattle. Additionally, in a project conducted by Pinkerton (1993) in which levels of 500 and 200 IU per d for 211 d prior to slaughter it was concluded that there were no lean color differences at d 1 of display. However, there were discernible differences after 8 d of retail display.

Meat Color Analysis

Isaac Newton initially discovered the concept of a color spectrum by separating light into colors through a prism. This allows the human to eye see color because the human retina is stimulated by differing wavelengths. A wavelength can be defined as the region found between the peaks of two adjacent waves. Red color has the longest wavelength while violet has the shortest wavelength. The only portion that is visible to the human eye is the called the visible region. As we move away from the visible wavelengths we encounter the infrared region which is made up of long wavelengths and the ultraviolet region which contains short wavelengths.

Hunt and co-workers (1980) define meat color as an opaque non-metallic object that refracts light at several different angles producing a diffuse reflectance. Minolta (1994) suggests that color is perceived differently by different people and is subject to interpretation. They also state that verbal descriptions of color are too complicated difficult to understand. The above reasons have lead researchers at the Minolta Corporation to develop a standardized method of color measurement.

The three primary attributes that make up color are hue, lightness and saturation (Minolta, 1994). Hue is most commonly used to describe different color classifications. Lightness allows colors to be separated into dark and light categories that are measured independently of hue. Finally, saturation differentiates dull colors from bright colors in terms of vividness and is again measured independently of hue and lightness. Minolta (1994) indicated that the

L*a*b* color space (CIELAB) is the most popular method for measuring object color. L* measures lightness, a* indicates the red to green color direction and b* measures the blue to yellow color direction. The Minolta colorimeter is widely used to express color values numerically opposed to subjective expressions given by human panelists (Minolta, 1994).

However, human panelists are still very important in determining the color and acceptability of fresh beef. Meat selection by consumer panelists has been based on many characteristics over the past several years (Hunt, 1980). Trained panelists are asked to evaluate fresh beef products for lean color, fat color, percent discoloration and overall acceptability. These scores are a nice compliment to the instrumental analysis scores provided by the Minolta colorimeter device.

Natural Antioxidants

An antioxidant is any substance that when found in food or the body at concentrations lower than those of oxidizable substrate delay or reduce the oxidation of that substrate. Many food manufacturers use antioxidants to increase the quality of their products as well as increase their nutritional value. Antioxidants have been shown to decrease or reduce oxidation in the following ways: 1) decreasing oxygen consumption 2) intercepting singlet oxygen 3) scavenging free radicals and 4) binding to metal ions (Shahidi, 1996).

There are several major advantages of using natural antioxidants. Natural antioxidants tend to be more easily accepted by the American consumer

(Rajalakshmi and Narasimhan, 1996). They also generally consider natural antioxidants such as rosemary and sage to be simply spices instead of preservatives or even forms of antioxidants (Turner et al.). Another major benefit of natural antioxidants is that the government more easily regulates them. Rajalakshmi and Narasimhan, 1996 stated that in many countries there is no testing required of antioxidants if the source is a food product that is considered safe. There is much concern about the fact that synthetic antioxidants have been shown to cause serious health problems while the opposite is true for natural substances.

Spices have been discovered to be one of the main sources of naturally occurring antioxidants. Chipault and co-workers (1956) discovered that allspice, rosemary, cloves, thyme, sage and oregano all exhibited antioxidant properties when combined with lard. The spices were combined with the lard by simply grinding them together. In later studies conducted by Chipault (1956), it was proven that of all of the spices previously mentioned, sage and rosemary showed the most promise for use in the meat industry. More recently, Six and others (1994) discovered that ascorbic acid also demonstrated antioxidant properties. This research proves that natural antioxidants can be effective in prolonging the shelf-life of certain meat items and was the basis for the current research project.

CHAPTER III

COMPARISON OF VITAMIN E AND NATURAL ANTIOXIDANTS ON THE LEAN COLOR AND RETAIL CASELIFE OF GROUND BEEF

A.E. Down, J.B. Morgan K. E. Nanke and H.G. Dolezal

ABSTRACT

Beef trimmings from cattle supplemented with either 0 or 500 IU/head/day of α-tocopherol acetate were obtained and divided into the following treatments: control (CON), vitamin E (VITE), Duralox® (DURA), a rosemary based natural antioxidant product, and Herbalox® (HERB), a natural antioxidant product consisting of rosemary and citric acid. Natural antioxidant products DURA and HERB were added to non α-tocopherol supplemented beef trimmings at 0.25% and 0.20% of meat weight, respectively. Products were packaged using an oxygen permeable film and exhibited in a commercial display case at 2°C ±1°C for 6 d. Objective and subjective measures of display lean color were taken twice daily. Lipid oxidation (TBARS) was measured on 0, 2, and 4 d of display for each treatment group. Packages representing CON treatment displayed increased ($P < .01$) TBARS values for the overall display period when compared to DURA, HERB and VITE treatments. Treatment groups VITE, DURA and HERB exhibited stable lipid properties (TBARS) especially after 4 d of display. Ground beef packages from VITE, DURA and HERB

treatments groups maintained their lean color for a longer portion of the display compared to CON, this was especially noticed following 3 d of display. L* mean values were higher ($P < .05$) for VITE, DURA and HERB treatments as compared to the CON group. Mean a* values across all display days were significantly higher ($P < .05$) for VITE and DURA treatment groups when compared to their CON opponents. Treatment groups VITE, DURA and HERB exhibited an increase in lean color acceptability, or the number of days required to reach a lean color score of 4.5, of 1.21, 0.81 and 0.65 d, respectively, when compared to their CON counterparts. The same treatment groups also increased the numbers of days required to reach an overall acceptability score of 4.5 by 0.94, 0.51 and 0.44 d, respectively, compared to CON product. Results of this trial suggests that both vitamin E and natural antioxidants can be beneficial in maintaining lipid stability and prolonging the case-life of ground beef packages.

INTRODUCTION

Today's fast track consumers *expect* to purchase products that are high in quality and nutritional value. In recent years, the quest to improve "quality" has become the underlying theme of retailers and resturaunteurs in the U.S. beef industry. Any product that deviates from the consumers perception of quality generally results in an "inferior" experience on the behalf of the customer. Perhaps Berry and Parasurman (1991) said it best, "From the customer's perspective, the proof of a service is its flawless performance." The service that the beef industry is responsible for providing to the American consumer is its

product. This makes it essential to provide beef consumers with a high quality product that meets their expectations every time they purchase beef.

Consumers are able to detect differences in color among beef products at the retail level and make purchasing decisions based on those differences. It has been estimated that between 2% and 20% of all beef products are discounted, discarded or further processed due to discoloration and consumer perceptions of the product being rancid (Sherbeck et al., 1995). Retailers are often forced to increase the price of all of their beef products in order to compensate for the monetary loss associated with discounting and discarding beef products. This could attribute to the fact that the beef industry has lost more than 25% of their market share since 1976 (USDA, 1997). If this trend continues, it is expected that they will control only 26 total percent of market share by the year 2005. In order for the beef industry to regain lost market share it will be imperative to provide the consumer with a fresh bright cherry red product.

The bright cherry red color that is associated with freshness is caused when the meat surface is exposed to oxygen and becomes oxygenated. After the product "blooms", or becomes fully oxygenated, pigments start to oxidized to the metmyoglobin state. Once 70% of the myoglobin becomes oxidized the meat surface becomes discolored or brown. Meat becomes oxidize after it is exposed to oxygen for 30 minutes and continues for about 3 days when displayed in a retail environment (Smith et al., 1996).

Extensive research indicates that feeding elevated levels of Vitamin E during the finishing phase will help prolong the case-life of beef and beef

products. Vitamin E acts as a free radical scavenger that is helpful in reducing or delaying lipid oxidation (Faustman et al., 1998). Wong and co-workers (1995) indicated that natural antioxidants such as rosemary, sage and ascorbic acid can also be used to delay the onset of lipid oxidation. Therefore, the use of natural antioxidants extends the time frame in which products can be sold for their initial or "full" market value. This study was conducted to determine if natural (Herbalox and Duralox) and synthetic (Vitamin E) antioxidants are effective in stabilizing red meat color and prolonging the case-life of ground beef products in simulated retail conditions.

EXPERIMENTAL PROCEDURES

Meat Samples

Beef trimmings (85 percent lean) from cattle supplemented with either 0 or 500 /IU/hd/d, were obtained from a commercial fabrication facility. Treatment groups were coarse ground using a 0.94 cm diameter plate and finely ground using a 0.32 diameter cm plate. Natural antioxidants Duralox™ and Herbalox™ were added to a portion of non-Vitamin E supplemented coarse ground beef trimmings at 0.25% and 0.20% of the total meat weight, respectively, and allowed to mix for approximately 10 min. During the final grind, ground beef packages (approximately 454 g) were assembled by placing a foam tray lined with a Dry-loc pad (Sealed Air Corp., Patterson, NC) beneath the grinder head and evenly distributing the meat onto the tray in order to reduce further handling. Following traying, ground beef packages were overwrapped with oxygen permeable film.

Each treatment group was packaged separately and 25 packages comprised each group. On d 0, 2, and 4 of retail display, duplicate samples were taken from each treatment and frozen to –20°C for further analyses of thiobarbituric acid concentration.

Retail Case-life Display

At the completion of packaging each treatment group, packages were placed in a commercial display case under cool-white florescent light (1600 to 1900 lux) at a temperature of 2° to 4°C for 6 d. Packages were randomly arranged in the display case at the beginning of each day. Twice daily, using a Minolta colorimeter (Minolta Co. Ltd., Osaka, Japan). L*, a* and b* values were obtained and recorded for each sample during the six d of retail display. Measurements were recorded at medial, central and lateral portions of each sample at each designated evaluation time. Samples were also visually evaluated by a trained 3 member panel twice daily for the following attributes: lean color (8 = bright cherry-red, 1 = extremely dark brown), fat color (8 = creamy white, 1 = dark-brown or green), percent discoloration (7 = none, 1 = complete) and overall appearance (7 = extremely desirable, 1 = extremely undesirable) (Sanders et al., 1997). Overall acceptability scores were used to measure the combined effects of all of the attributes and to determine consumer acceptability of the product.

Thiobarbituric Acid Analysis

Duplicate samples from each treatment were removed from ground the beef packages on 0, 2, and 4 days of display for Thiobarbituric Acid Analysis (TBA analyses). The TBA procedure was performed using the test procedure outlined by Witte et al. (1970). The following modifications were made to the procedure: a 10 g sample was extracted and 30 ml of the slurry was centrifuged at 3000 RPM for 30 min prior to filtration. The results were recorded as thiobarbituric acid reactive substances (TBARS) which represent mg malondialdehyde (MDA) equivalents per kg of fresh beef.

Statistical Analysis

The least squares means option of the General Linear Model procedure of the SAS program (SAS, Cary, NC) was used to compare means for the overall treatment effect as well as each treatment by day interaction. Acceptability ranges of objective and subjective ratings for lean color and overall acceptability were calculated using regression equations to determine the number of hours required to reach a score of 4.5 (unacceptable) or lower. The frequency procedure of the SAS program was performed to determine how many packages reached 4.5 or lower per treatment per day in order to decide how many packages were considered unacceptable per day.

RESULTS AND DISCUSSION

Lipid Oxidation

Thiobarbituric acid reactive substances (TBARS) were used to determine the amount of lipid oxidation at 0, 2 and 4 days of display. A significant treatment x day interaction was observed in that packages from the CON treatment exhibited significantly higher ($P < .05$) TBARS values on each day of measurement compared to the VITE, DURA and HERB groups which were not significantly different from each other (Table 1). This supports the findings of Mitsumoto et al. (1993) who concluded that dietary supplementation of Vitamin E suppressed lipid oxidation in ground beef for up to 9 d of retail display. Faustman et al., 1989b also found that sirloin patties from carcasses of cattle supplemented with Vitamin E had lower TBA values than non-supplemented cattle.

Subjective color analysis

Mean panelist lean color ratings suggested that the VITE, DURA and HERB treatments maintained a higher ($P < .05$) rating for red color for each day of retail display on days 0 through 4 than did their CON counterparts (Figure 3.1). Additionally, on the final day of display, packages from the VITE treatment also exhibited more desirable ($P < .05$) lean color scores than the CON, DURA and HERB groups (Figure 3.1). This supports the findings of Sanders et al. (1997) which concluded that steaks from steers supplemented with Vitamin E were significantly brighter ($P < .05$) than steaks from non-supplemented cattle. Figure

3.8 shows that treatment groups VITE, DURA and HERB also exhibited an increase in lean color acceptability of 1.21, .81 and .65 days, respectively when compared to their CON counterparts. It was concluded that at 3 d of display, 84% of CON packages should be removed from the display case due to inferior lean color while only 8%, 28% and 24% of VITE, DURA and HERB packages reached an overall score of 4.5, respectively (Table 2). These data support the findings of Sherbeck and others in 1995 that indicated that 17.9% of conventionally-processed ground chuck products were discounted in price as a result of inadequate shelf-life while only 2.3% of VITE packages were discounted. Visual assessment of fat color indicated that the VITE treatment received significantly higher ($P < .05$) ratings on d one through five of display when compared to packages representing the CON, DURA and HERB treatments (Figure 3.2). However, packages containing DURA and HERB displayed greater ($P < .05$) ratings for fat color than did the CON treatment on days 1 through 4 of display. Packages from the VITE treatment displayed greater mean percent discoloration scores ($P < .05$) than CON packages after d 1 of display and were more desirable ($P < .05$) than DURA and HERB after 3 d of display. Treatment groups DURA and HERB also exhibited significantly higher percent discoloration scores than CON after 1 d of retail display while the DURA treatment was more desirable ($P < .05$) than HERB on display d 3 and 4. In a similar study conducted by Sanders et al. (1997) steaks from steers supplemented with Vitamin E received more desirable ($P < .05$) ratings for surface discoloration than steaks from non-supplemented cattle. Overall

appearance scores show that while no significant differences were recorded on d 0, VITE, DURA and HERB treatments received significantly higher ($P < .05$) scores when compared to CON on d 1 through 4 of display (Figure 3.4). On the final day of display (i.e., d 5), the VITE supplemented ground beef packages maintained a significantly higher ($P < .05$) mean rating for overall appearance than CON, DURA and HERB packages which were not significantly different ($P < .05$) from each other. Results included in figure 1.9 illustrates that the VITE, DURA and HERB treatments extended the case-life of ground beef packages by 0.94, 0.51 and 0.44 days, respectively when compared to the CON group. At 3 d of display, 84% of CON packages had reached an overall acceptability score of ≤4.5 while only 8%, 28% and 36%, of VITE, DURA and HERB packages, respectively, had scores of ≤4.5 (Table 2).

Objective Color Measurements

Treatment groups VITE, DURA and HERB displayed higher ($P < .05$) L* values on each day of display when compared to CON packages (Figure 3.5). On the final day of display, packages representing the VITE treatment exhibited higher ($P < .05$) L* values when compared their DURA and HERB counterparts. Minolta a* mean values revealed that packages from the CON treatment received significantly lower ($P < .05$) ratings on d 2 and 3 of display when compared to VITE, DURA and HERB packages (Figure 3.6). Although no significance was detected, the CON treatment also had the lowest mean Minolta a* value on the final day of display. Minolta b* values indicated that the VITE

treatment maintained higher ($P < .05$) values on each day of display than did the CON packages (Figure 3.7). Additionally, on days 1 through 5 of display, packages from the DURA and HERB treatments were also showed higher ($P < .05$) Minolta b* values when compared to the CON packages.

IMPLICATIONS

Using antioxidant to prolong the case-life of meat products is one tactic that can be used by the beef industry to help improve consumer perceptions of beef as well as help regain already lost marketshare. Results of this study suggest that feeding supplemental vitamin E as well as supplementing meat with natural antioxidant products could improve lean color and prolong retail case-life of ground beef products.

CHAPTER IV

COMPARISON OF VITAMIN E, NATURAL ANTIOXIDANTS AND ANTIOXIDANT COMBINATIONS ON THE LEAN COLOR AND RETAIL CASELIFE OF GROUND BEEF

A.E. Down, J.B. Morgan, K. E. Nanke and H.G. Dolezal

ABSTRACT

Beef trimmings from cattle supplemented 0 or 500/IU/head/day were obtained and divided into the following treatment groups: Control (CON), Vitamin E (VITE), Duralox (DURA) and Vitamin E/Duralox combination (COMBO). Trimmings were initially ground using a 1.25 cm diameter plate. Duralox™ natural antioxidant was added to the DURA and COMBO groups at 0.25% of the meat weight. After coarse grinding the treatment groups were vacuum packaged and stored for 5 d prior to being finely ground twice with a .32 cm grinding plate. Ground beef patties (approximately 114 g) were placed on foam trays and overwrapped with oxygen permeable film. Packages were displayed for 5 d at 2°C ± 1°C in retail display cases. Twice daily, objective and subjective measurements of lean color were taken. Lipid oxidation (TBARS) was measured immediately following the initial grind and at 0, 2, and 4 days of display.

CON patties had increased ($P < .01$) TBARS values across the entire display period while VITE, COMBO and DURA treatments did not differ.

Patties from treatment groups VITE and COMBO maintained their red lean color for a longer portion of the display period than did their CON and DURA counterparts. Packages from VITE and COMBO treatments had higher a* values ($P < .05$) across all display days than did the CON and DURA groups. Mean values for lean color, fat color, percent discoloration and overall appearance were higher ($P < .05$) for both the VITE and COMBO treatment groups. Packages from VITE, COMBO and DURA treatment groups showed an increase in lean color acceptability by 0.94, 0.54 and 0.44 d, respectively. They also showed an increase in overall acceptability by 1.36, 0.11 and 0.22 d, respectively. Results of this study suggest that feeding supplemental Vitamin E can be used to prolong beef color and case-life.

INTRODUCTION

Today's fast track consumers *expect* to purchase products that are high in quality and nutritional value. In recent years "quality" has become the underlying theme of retailers and restaurateurs in the U.S. beef industry. Any product that deviates from the consumers perception of quality generally results in a "inferior" experience on the behalf of the customer. Perhaps Berry and Parasurman (1991) said it best, "From the customer's perspective, the proof of a service is its flawless performance." The United States beef industry provides the customer its product as a service. This makes it essential to provide beef consumers with a high quality product that meets their expectations every time they purchase beef.

Consumers are able to detect differences in color among beef products at the retail level and make purchasing decisions based on those differences. It has been estimated that between 2 and 20% of all products are discounted, discarded or further processed due to discoloration and consumer perceptions of the product being rancid (Sherbeck et. al., 1995). Retailers are often forced to increase the price of all of their beef products in order to compensate for the monetary loss associated with discounting and discarding beef products. This could attribute to the fact that the beef industry has lost more than 25% of their market share since 1976. If this trend continues, it is expected that they will control only 26 total percent of market share by the year 2005. In order for the beef industry to regain lost market share it will be imperative to provide the consumer with a fresh bright cherry red product.

The bright cherry red color that is associated with freshness is caused when the meat surface is exposed to oxygen and becomes oxygenated. After the product "blooms", or becomes fully oxygenated, pigments start to oxidized to the metmyoglobin state. Once 70% of the myoglobin becomes oxidized the meat surface becomes discolored or brown. Meat becomes oxidized after it is exposed to oxygen for 30 minutes and continues for about 3 days when displayed in a retail environment (Smith et. al., 1996).

Recent research indicates that natural antioxidant supplementation helps improve the case-life of beef by delaying the onset of oxidation. Feeding elevated levels of Vitamin E during the finishing phase has shown to reduce lipid oxidation by serving as a free radical scavenger (Faustman 1998). There has

also been work done suggesting that natural antioxidants such as rosemary, sage and ascorbic acid can also prolong beef shelf life and help maintain the red color that is associated with a fresh product. Research done by Wong et. al., concludes that Vitamin E can be combined with other natural antioxidants such as rosemary and sage to further prevent the onset of lipid oxidation. The purpose of this project is to determine if natural antioxidants, synthetic antioxidants and antioxidant combinations (Vitamin E, Herbalox and Duralox) are effective in prolonging acceptable lean color and increasing the case-life of beef products.

EXPERIMENTAL PROCEDURES

Meat Samples

Beef trimmings from cattle supplemented with either 0 or 500 IU/hd/day, consisting of approximately 85% lean, were obtained from a commercial fabrication facility. Treatment groups were individually coarse ground using a 1.27 cm diameter plate before Duralox™, a natural antioxidant, was added to both Vitamin E supplemented and non-Vitamin E supplemented ground trimmings at 0.25% of the total meat weight. Treatments supplemented with Duralox™ were then allowed to mix for a period of 10 minutes. The coarse ground product was then stuffed into chubs, vacuum packaged and stored (5°C) in the dark for a period of 5 days. Following a 5 d storage period, the coarse ground product was finely ground twice through a .32 cm plate to ensure even fat distribution. Ground beef patties (approximately 114 g) were formed using a plastic patty former and placed on foam trays without absorbent pads and

overwrapped with oxygen permeable film. Each treatment group was packaged separately and 25 patties comprised each group. Two 10 gram samples were removed from each treatment group following the initial grind and frozen (–20°C) for subsequent analysis of thiobarbituric acid concentration (TBARS). Additionally, duplicate samples were also taken on d 0, 2 and 4 of retail display, and frozen to –20°C for further analyses of thiobarbituric acid concentration.

Packages were placed in a commercial display case under cool-white florescent light (1600 to 1900 lux) at a temperature of 2° to 4°C for six d of display. Packages were randomly arranged in the display case at the beginning of each day. Twice daily (8:00 A.M. and 4:30 P.M.) using a Minolta colorimeter (Minolta Co. Ltd., Osaka, Japan), L*, a* and b* values were obtained and recorded for each sample during the six d of retail display. Measurements were recorded at medial, central and lateral portions of each sample at each designated evaluation time. Samples were also visually evaluated by a trained 3 member panel during the same time periods on each display day for the following attributes: lean color (8 = bright cherry-red, 1 = extremely dark brown), fat color (8 = creamy white, 1 = dark-brown or green), percent discoloration (7 = none, 1 = complete) and overall appearance (7 = extremely desirable, 1 = extremely undesirable) (Sanders et al., 1997). Overall acceptability scores were used to measure the combined effects of all of the attributes and to determine consumer acceptability of the product.

Thiobarbituric Acid Analysis

Duplicate samples were removed from ground beef patties on 0, 2 and 4 days of display for Thiobarbituric Acid Analysis (TBA). The TBA procedure was performed using the test procedure outlined by Witte et al. (1970). The following modifications were made to the procedure: a 10 gram sample was extracted, and 30 ml of the slurry was centrifuged at 3000 RPM for 30 minutes prior to filtration. The results were recorded as thiobarbituric acid reactive substances (TBARS) which represent mg malomdialdehyde (MDA) equivalents per kg of fresh beef.

Statistical Analysis

The least squares means option of the General Linear Model procedure of the SAS program (SAS, Cary, NC) was used to compare means for each treatment over the entire display period as well as each treatment by day interaction. Acceptability ranges of objective and subjective ratings for lean color and overall acceptability were calculated using regression equations to determine the number of hours required to reach a score of 4.5 or less. The frequency procedure of the SAS program was performed to determine how many packages reached scores of 4.5 or less (i.e., unacceptable) per treatment per day in order to calculate how many packages were considered unacceptable per day.

RESULTS AND DISCUSSION

Lipid Oxidation

Thiobarbituric acid reactive substances (TBARS) were used to measure the amount of lipid oxidation prior to storage and on d 0, 2 and 4 of display.

Treatment x day interactions are listed in Table 4. The CON treatment group had higher ($P < .05$) TBARS values at each sampling period. On the final sampling day, the COMBO treatment had the numerically lowest TBA value although not significantly different from either DURA or VITE. This suggests that natural antioxidants could have an additive effect with synthetic antioxidants in reducing rancidity. This supports research conducted by Mitsumoto et. al., 1991 that concluded steaks dipped in Vitamin C prior to display decreased ($P < .05$) mean TBA values when compared to non-dipped steaks. However, this theory contradicts the results of Wong et al., (1995) that indicated that the addition of rosemary and sage to Vitamin E did not reduce TBARS values when compared to Vitamin E alone.

Subjective Color Analysis

Mean panelist color score ratings indicated that patties representing the VITE treatment maintained a more desirable ($P < .05$) lean color for a longer portion of the display, especially after d 2 when compared to CON, DURA and COMBO patties (Figure 4.1). This supports the findings of Sanders et al., (1997) which concluded that steaks from steers supplemented with Vitamin E were brighter ($P < .05$) than steaks from non-supplemented cattle. Additionally, the VITE, DURA and COMBO treatments extended the amount of time required to reach a lean color score of 4.5, unacceptable lean color, by 0.94, 0.44 and 0.54 days, respectively. At 2 d of display, 100% of CON and 40% of DURA packages reached a lean color score of 4.5 compared to 0% for both VITE and COMBO

packages. This data supports the findings of Sherbeck et al., (1995) who indicated that 17.9% of CON ground chuck products were discounted while only 2.3% of VITE packages reached a color associated with discounts. The VITE group also exhibited the greatest fat stability ($P < .05$) when compared to the CON, DURA and COMBO treatments especially after 3 d of display. The CON treatment showed the most fat discoloration ($P < .05$) at 5 d of display when compared to DURA, VITE and COMBO patties (Figure 4.2). Patties from the VITE treatment received higher ($P < .05$) mean values for percent discoloration especially after 3 d of display when compared to CON, DURA and COMBO while they were not significantly different from COMBO on the final measurement day (Figure 4.3). There were no treatment x day interaction for percent discoloration means for d 0 through 2 of display. Mean values for overall appearance indicate that treatment groups VITE and COMBO were both more desirable ($P < .05$) than patties from DURA and CON treatments after d 0 of display with VITE patties being higher ($P < .05$) than COMBO until d 5 (Figure 2.4). Treatments VITE, DURA and COMBO extended the overall caselife of the ground beef patties by 1.36, 0.22 and 0.11 days, respectively (Figure 2.9). At 2 d of display, 20% of VITE, 100% of CON and 40% of DURA packages had reached an overall appearance score compared to 0% of COMBO patties (Table 6).

Objective Color Measurements

Treatment x day interactions for Minolta L* values are shown in Figure 4.5. Interestingly, VITE ground beef patties exhibited the lowest numeric values for L* readings on d 0 through 4 of display. The COMBO treatment displayed the

highest L* values on d 1 through 3 of display, while the CON treatment exhibited the highest mean L* value on the final display day. This could be attributed to the fact that certain shades of brown are often lighter than deep shades of red. This contradicts the results of the previous experiment that indicated the CON treatment exhibited lower ($P < .05$) L* values than its opposing treatment groups. Mean values for Minolta a* values indicated that VITE and COMBO treatments were redder throughout the entire display period than did patties representing the CON and DURA treatments (Figure 4.6). However, while the COMBO group maintained higher ($P < .05$) Minolta a* values on d 0 and 1 of display when compared to VITE, patties from the VITE group were redder ($P < .05$) on d 3 through 5 of display. Patties from the CON and DURA groups had lower ($P < .05$) a* mean values when compared to VITE and COMBO after d 1 of display.

IMPLICATIONS

The use of natural and synthetic antioxidants to improve and prolong the case-life of ground beef is one tactic that may be used by the beef industry to not only improve the image of beef and beef products, but to also help regain already lost marketshare. The results of this study show that the use of natural and synthetic antioxidants as well as antioxidant combinations may help improve the lean color and prolong the retail case-life of ground beef patties.

Table 1: Least squares means for TBARS values for each treatment by day combination.

	Treatment				
Attribute	Control	Vitamin E	Duralox	Herbalox	SEM
Day 0	.92[a]	.23[b]	.13[b]	.14[b]	.06
Day 2	.71[a]	.24[b]	.21[b]	.14[b]	.07
Day 4	1.90[a]	.33[b]	.18[b]	.19[b]	.01

Numbers with differing superscripts within the same row are significantly different ($P < .05$)

Table 2: Comparison of the percentage of packages reaching a lean color score of ≤ 4.5 on each day of display

	Treatment			
Day	Control	Vitamin E	Duralox	Herbalox
Day 2	24	0	0	0
Day 3	84	8	28	24
Day 4	100	40	72	88
Day 5	100	100	100	100

Table 3: Comparison of the percentage of packages reaching an overall appearance score of ≤ 4.5 on each day of display

	Treatment			
Day	Control	Vitamin E	Duralox	Herbalox
Day 2	8	0	0	0
Day 3	84	8	28	36
Day 4	100	84	100	100
Day 5	100	100	100	100

Table 4: Least squares means for TBARS values for each treatment by day combination

	Treatment				
Day	Combo	Control	Duralox	Vitamin E	SEM
Initial	.18[a]	.36[b]	.08[a]	.09[a]	.03
0	.07[a]	.39[b]	.07[a]	.18[a]	.03
2	.09[a]	.49[b]	.04[a]	.18[a]	.03
4	.11[a]	.60[b]	.23[a]	.32[a]	.03

Numbers with differing superscripts within rows are significantly different ($P < .05$)

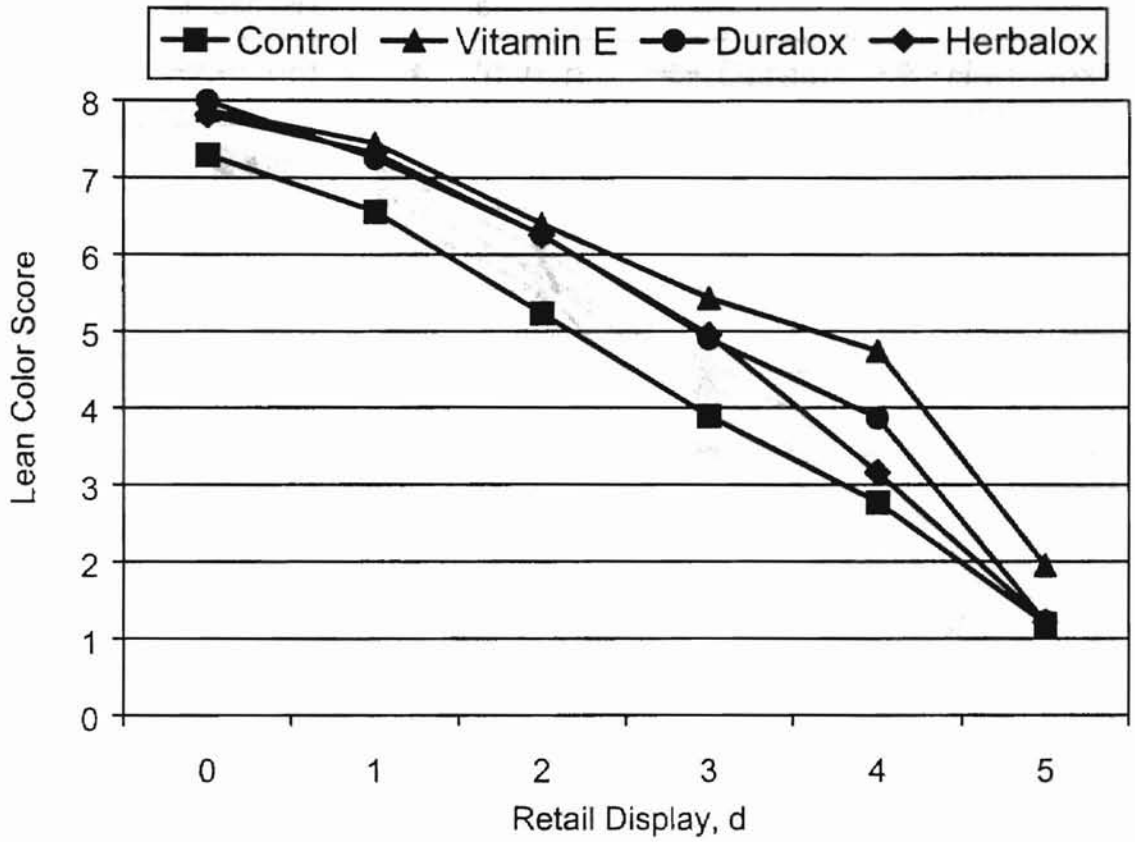
Table 5: Comparison of the percentage of packages reaching a lean color score of ≤ 4.5 on each day of retail display

	Treatment			
Day	Vitamin E	Control	Combo	Duralox
Day 2	0	100	0	40
Day 3	24	100	92	100
Day 4	72	100	100	100
Day 5	100	100	100	100

Table 6: Comparison of the percentage of patties reaching an overall acceptability score of ≤ 4.5 on each day of retail display

	Treatment			
Day	Vitamin E	Control	Combo	Duralox
Day 2	20	100	0	40
Day 3	44	100	92	100
Day 4	92	100	100	100
Day 5	100	100	100	100

Figure 3.1: Comparison of visual lean color scores for ground beef packages across all display days.

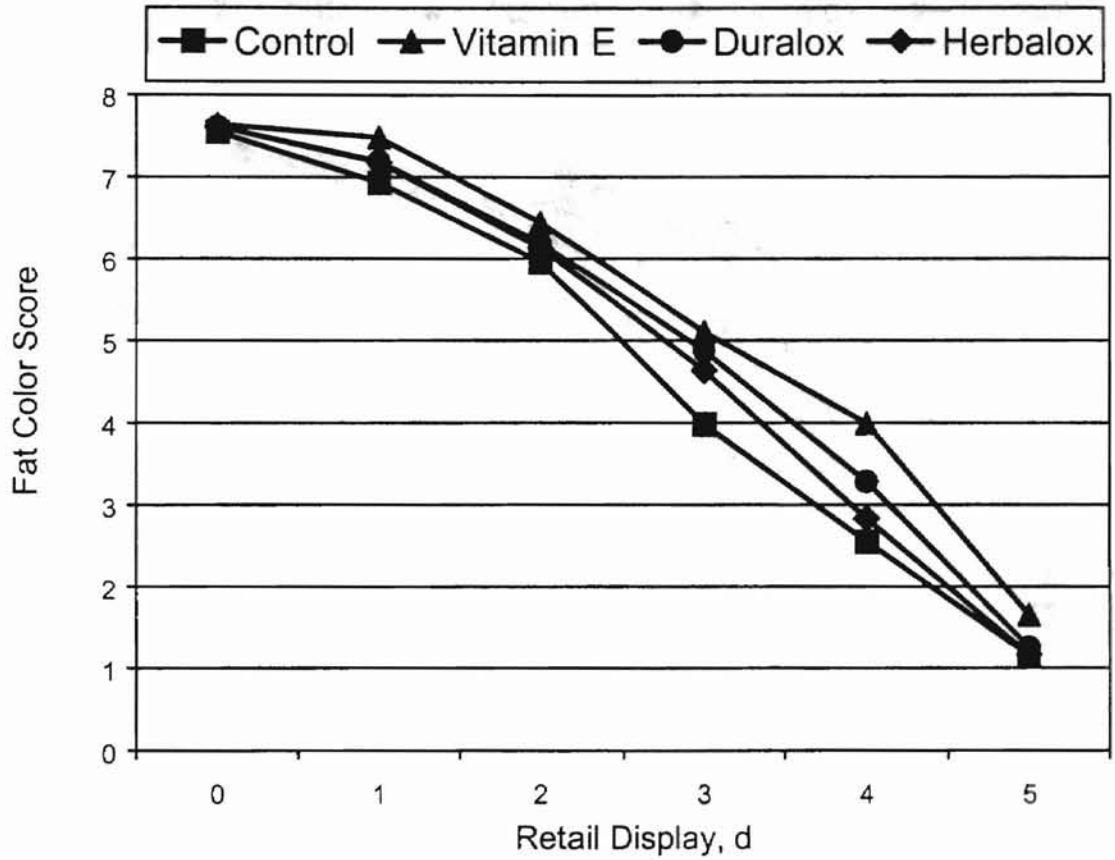


	Treatment[a]			
Day	Control	Vitamin E	Duralox	Herbalox
0	7.29^{cd}	7.87^{b}	7.97^{b}	7.81^{b}
1	6.56^{e}	7.45^{c}	7.25^{c}	7.32^{cd}
2	5.23^{h}	6.40^{ef}	6.26^{f}	6.25^{f}
3	3.89^{k}	5.43^{g}	4.91^{ij}	4.95^{i}
4	2.77^{m}	4.74^{j}	3.86^{k}	3.15^{l}
5	1.19^{o}	1.95^{n}	1.21^{o}	1.21^{o}

[a]SE= RSD*1/√n.

[b-o]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 3.2: Comparison of visual fat color scores for ground beef packages across all display days.

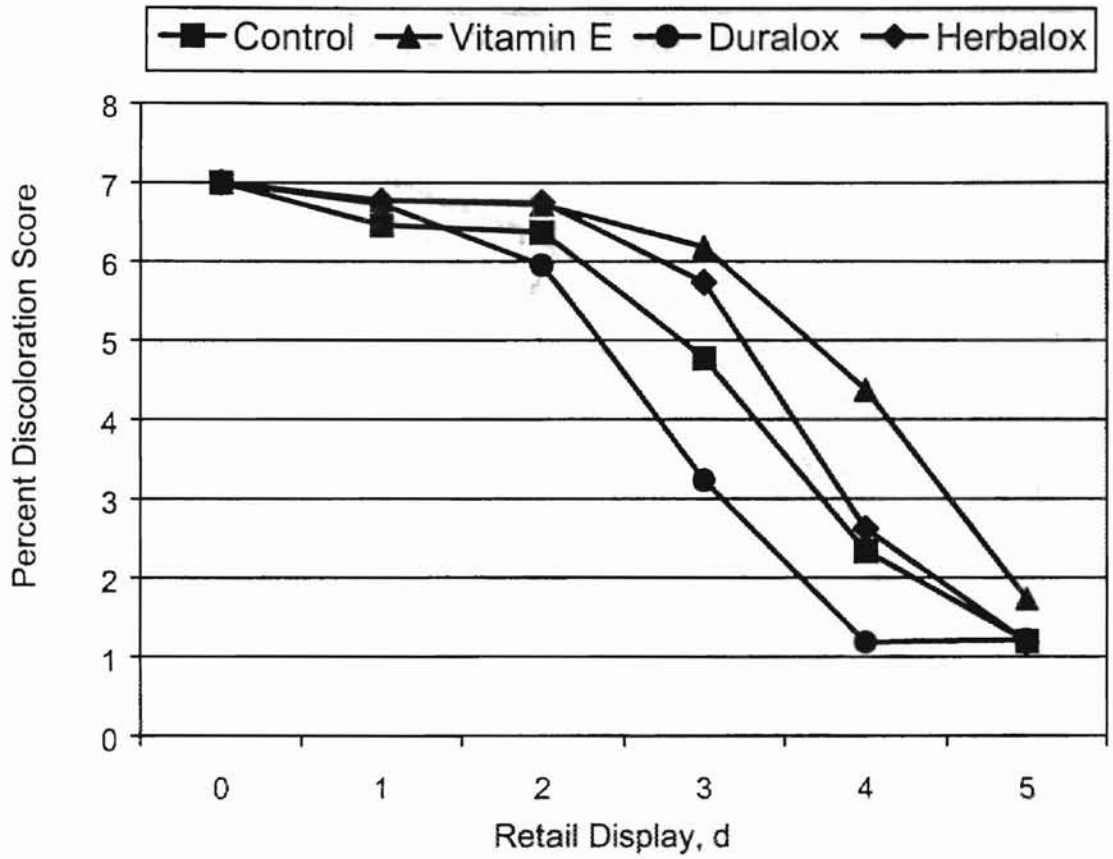


	Treatment[a]			
Day	Control	Vitamin E	Duralox	Herbalox
0	7.55^{b}	7.64^{b}	7.61^{b}	7.61^{c}
1	6.93^{d}	7.48^{b}	7.19^{c}	7.18^{c}
2	5.96^{g}	6.44^{e}	6.19^{f}	6.13^{fg}
3	3.98^{k}	5.10^{h}	4.87^{l}	4.63^{m}
4	2.55^{n}	3.99^{k}	3.28^{l}	2.83^{m}
5	1.15^{p}	1.65^{o}	1.25^{p}	1.16^{p}

[a]SE= RSD*1/√n.

[b-p]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 3.3: Comparison of visual percent discoloration scores for ground beef packages across all display days

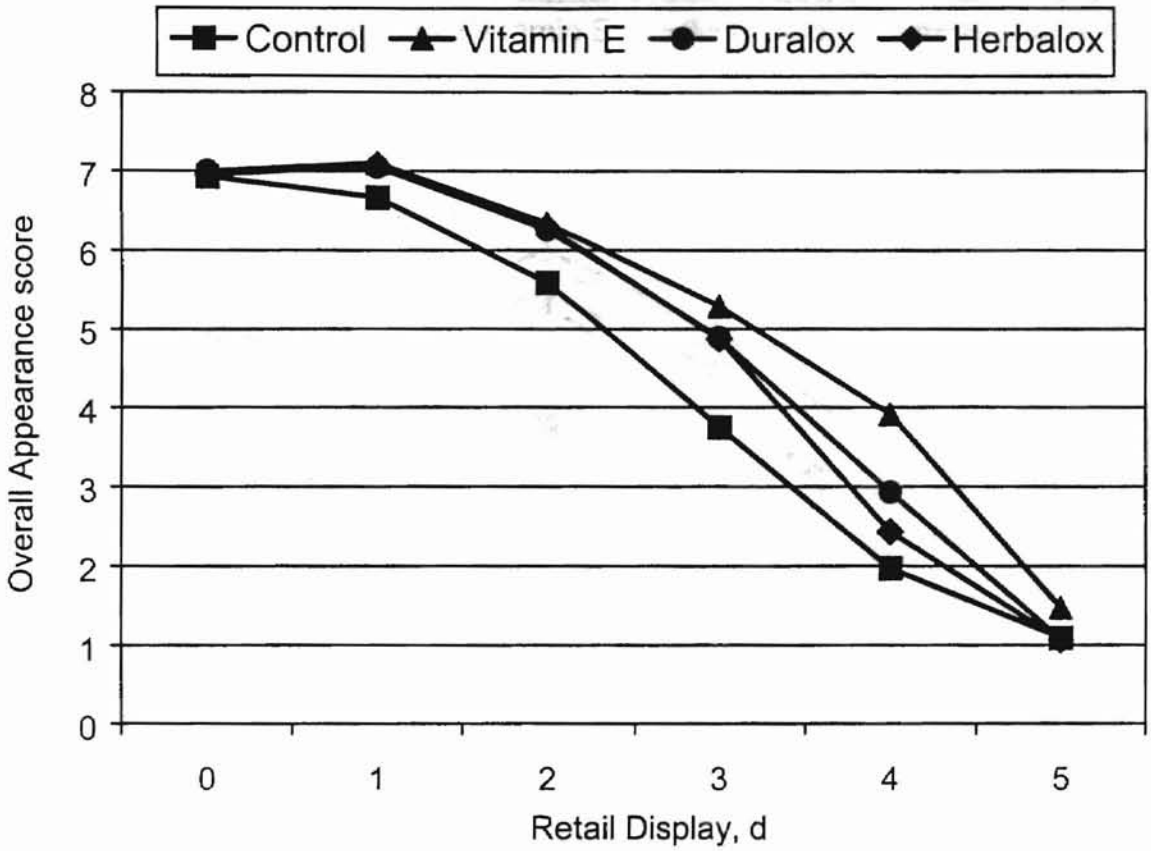


	Treatment[a]			
Day	Control	Vitamin E	Duralox	Herbalox
0	7.00[b]	7.00[b]	7.00[b]	7.00[b]
1	6.46[d]	6.77[c]	6.73[c]	6.77[c]
2	6.37[d]	6.72[c]	6.77[c]	6.75[c]
3	4.77[l]	6.18[f]	5.95[g]	5.73[h]
4	2.34[m]	4.37[j]	3.23[k]	2.62[l]
5	1.19[o]	1.73[n]	1.18[o]	1.18[o]

[a]SE= RSD*1/√n.

[b-o]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 3.4: Comparison of overall appearance scores for ground beef packages across all display days.

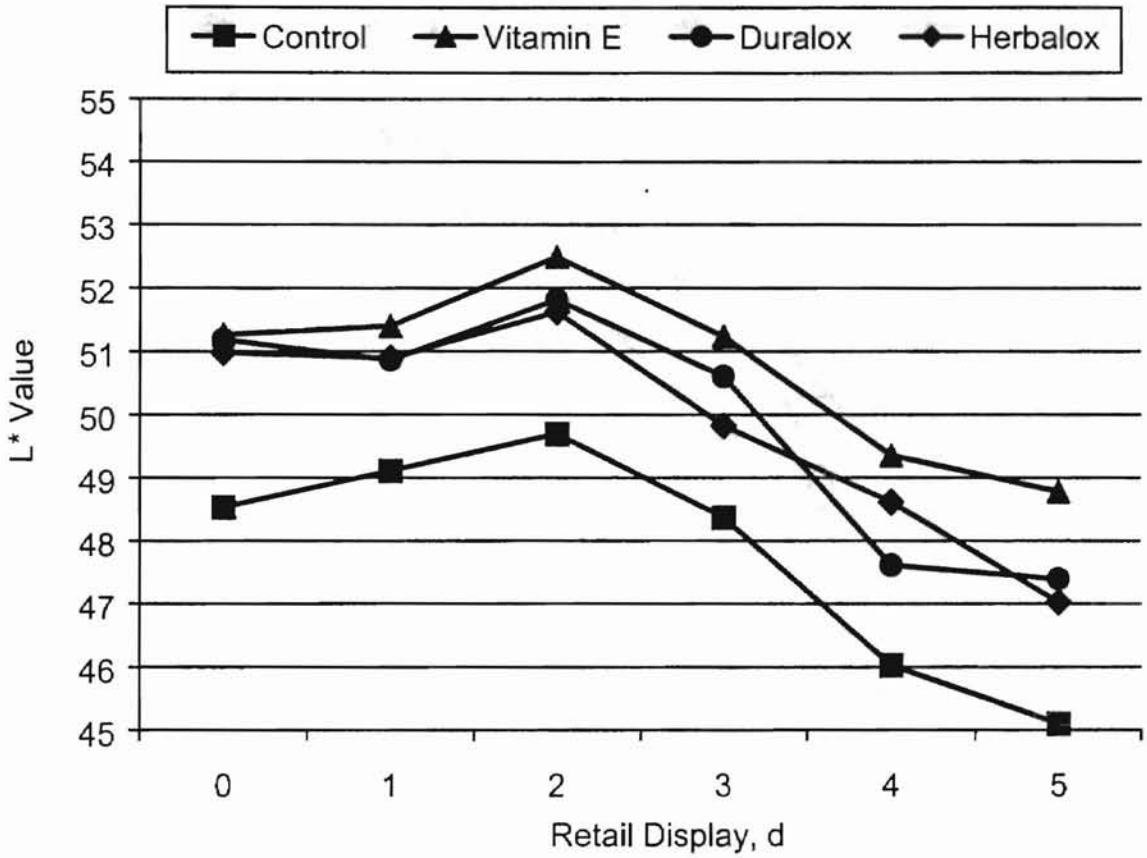


	Treatment[a]			
Day	Control	Vitamin E	Duralox	Herbalox
0	6.93^{bc}	6.99^{b}	7.00^{b}	6.95^{bc}
1	6.42^{d}	6.83^{c}	6.77^{c}	6.78^{c}
2	5.58^{f}	6.34^{de}	6.26^{e}	6.29^{de}
3	3.75^{j}	5.29^{g}	4.89^{h}	4.87^{h}
4	1.97^{m}	3.91^{i}	2.93^{k}	2.43^{l}
5	1.09^{o}	1.47^{n}	1.08^{o}	1.06^{o}

[a]SE= RSD*1/√n.

[b-o]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 3.5: Comparison of Minolta L* values of ground beef packages across all display days.

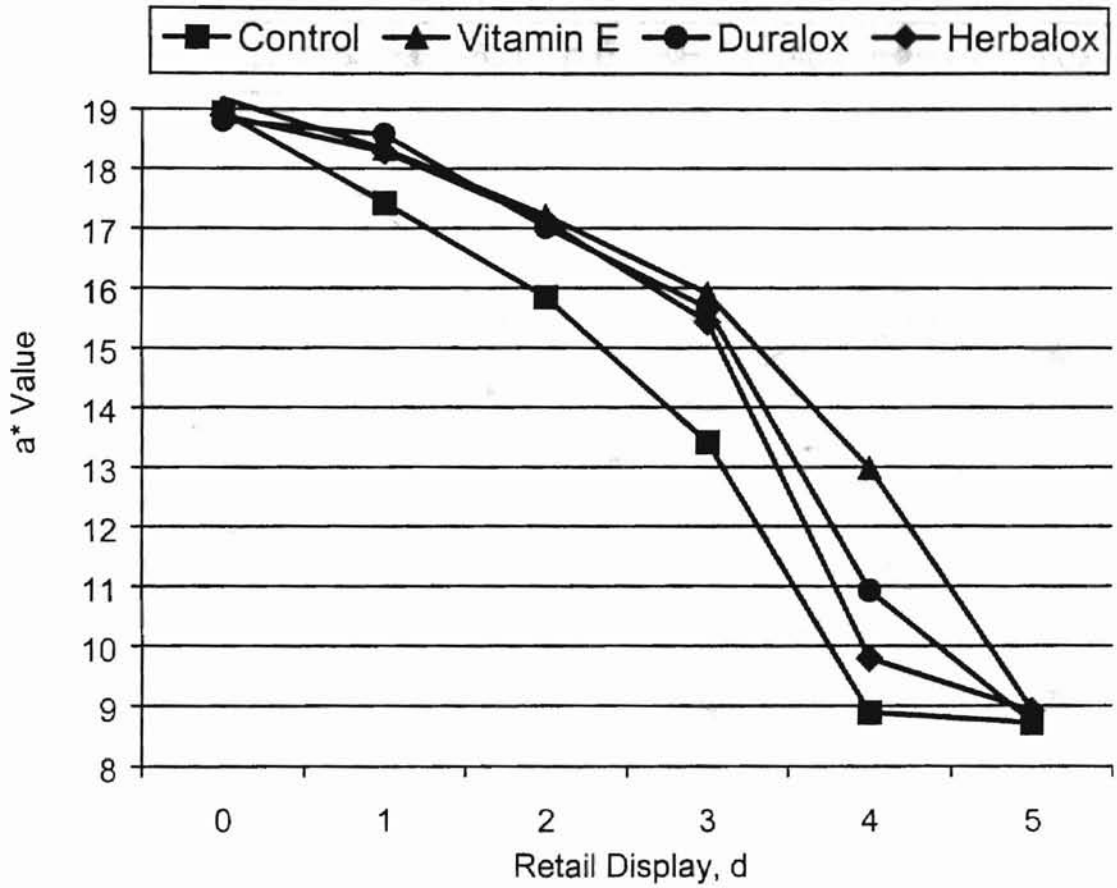


	Treatment[a]			
Day	Control	Vitamin E	Duralox	Herbalox
0	48.53^{hij}	51.26^{cde}	51.17^{cde}	50.98^{cde}
1	49.11^{ghi}	51.40^{cde}	50.86^{de}	50.89^{cd}
2	49.69^{g}	52.94^{b}	51.81^{bc}	51.62^{cd}
3	48.37^{ij}	51.23^{cde}	50.60^{ef}	49.82^{fg}
4	46.03^{l}	49.35^{gh}	47.61^{jk}	48.61^{hi}
5	45.10^{m}	48.78^{hi}	47.39^{k}	47.02^{k}

[a]SE= RSD*1/√n.

[b-l]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 3.6: Comparison of Minolta a* values of ground beef packages across all display days.

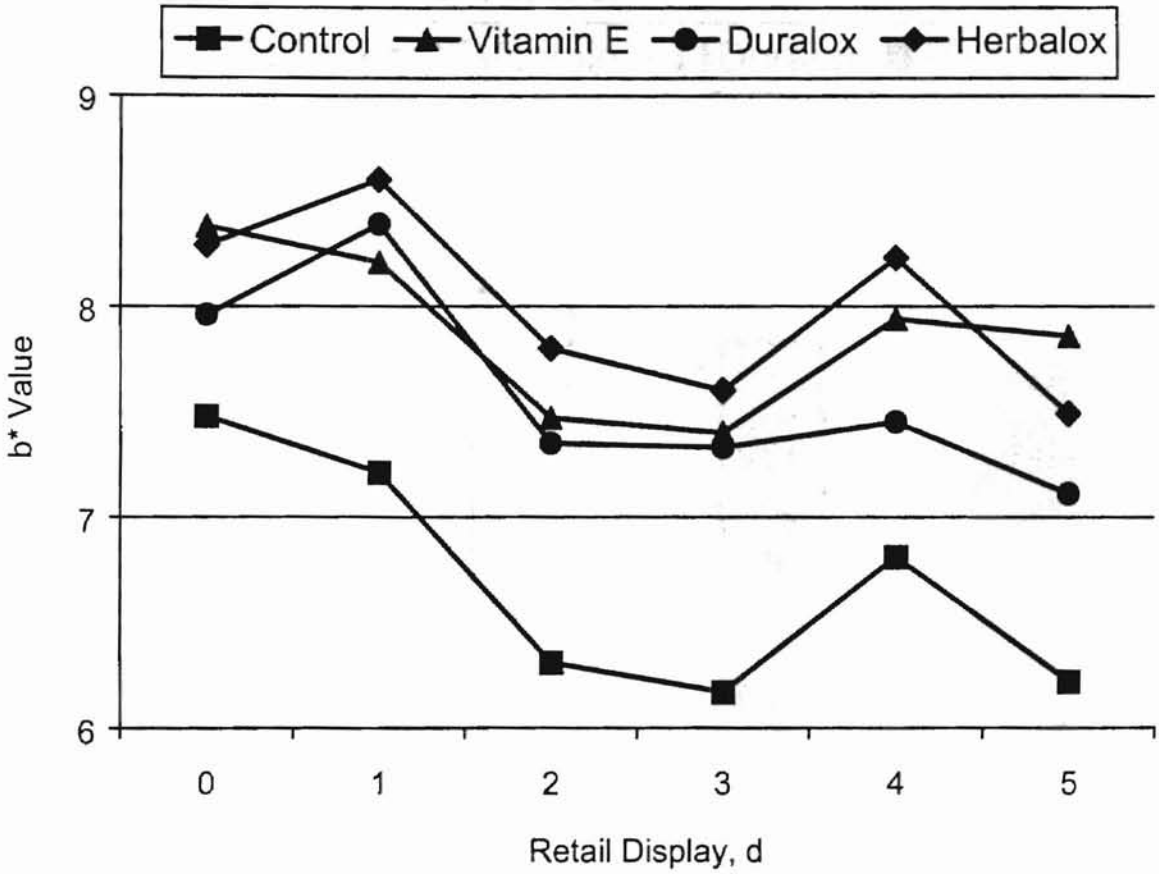


	Treatment[a]			
Day	Control	Vitamin E	Duralox	Herbalox
0	18.94[b]	19.17[b]	18.81[b]	18.89[b]
1	17.42[c]	18.33[bc]	18.57[b]	18.29[bc]
2	15.85[d]	17.21[c]	17.01[cd]	17.12[cd]
3	13.42[e]	15.91[d]	15.67[d]	15.43[d]
4	8.89[g]	12.98[e]	10.92[f]	9.79[fg]
5	8.72[g]	8.94[g]	8.73[g]	8.91[g]

[a]SE= RSD*1/√n.

[b-l]Numbers with differing superscripts within the same row are significantly different (P < .05).

Figure 3.7: Comparison of Minolta b* values for ground beef packages across all display days.



	Treatment[a]			
Day	Control	Vitamin E	Duralox	Herbalox
0	7.48^{de}	8.38^{bc}	7.96^{cde}	8.29^{bc}
1	7.21^{e}	8.21^{c}	8.39^{bc}	8.60^{b}
2	6.31^{g}	7.47^{e}	7.35^{e}	7.80^{d}
3	6.17^{g}	7.40^{e}	7.33^{e}	7.60^{d}
4	6.81^{f}	7.94^{cd}	7.46^{e}	8.23^{bc}
5	6.22^{g}	7.86^{cd}	7.11^{ef}	7.49^{de}

[a]SE= RSD*1/√n.
[b-m]Numbers with differing superscripts within the same row are significantly different (P < .05).

Figure 3.8: Comparison of the days required for each treatment group to reach a lean color score of 4.5

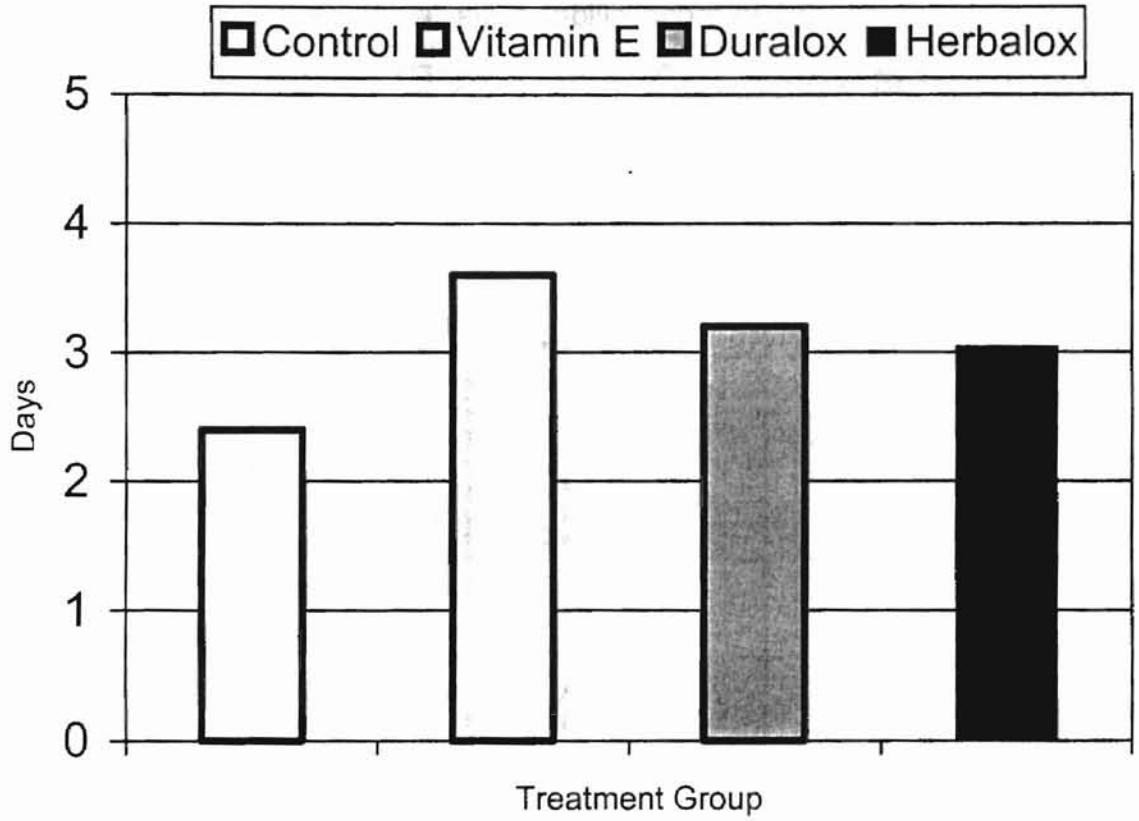


Figure 3.9: Comparison of the days required for each treatment group to reach an overall acceptability score of 4.5

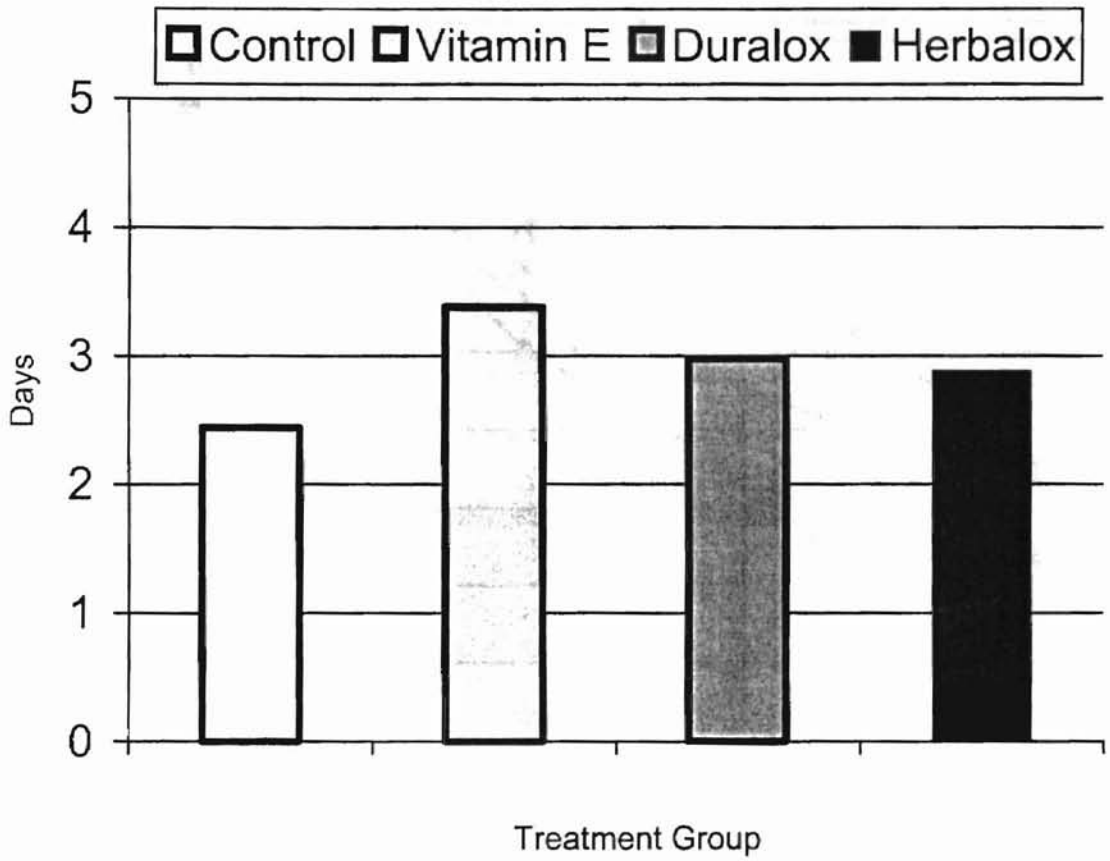
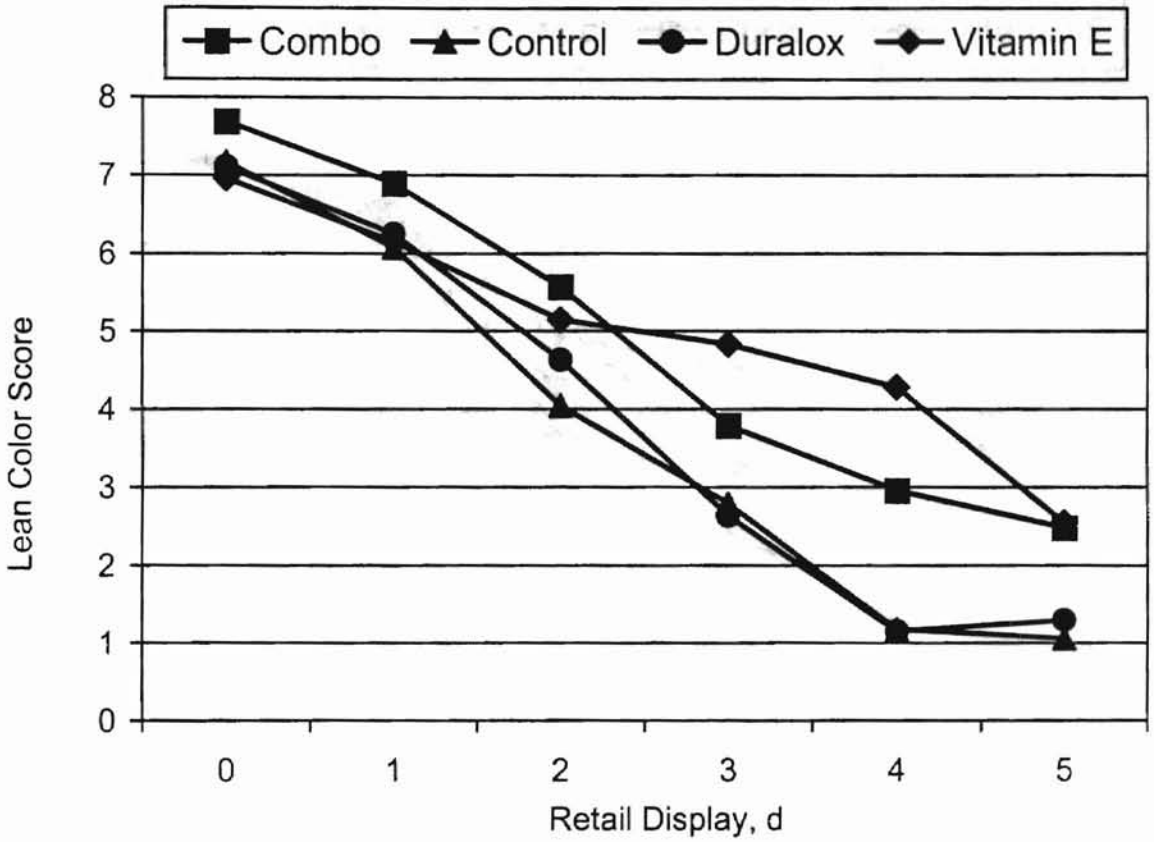


Figure 4.1: Comparison of visual lean color scores of ground beef patties across all display days.

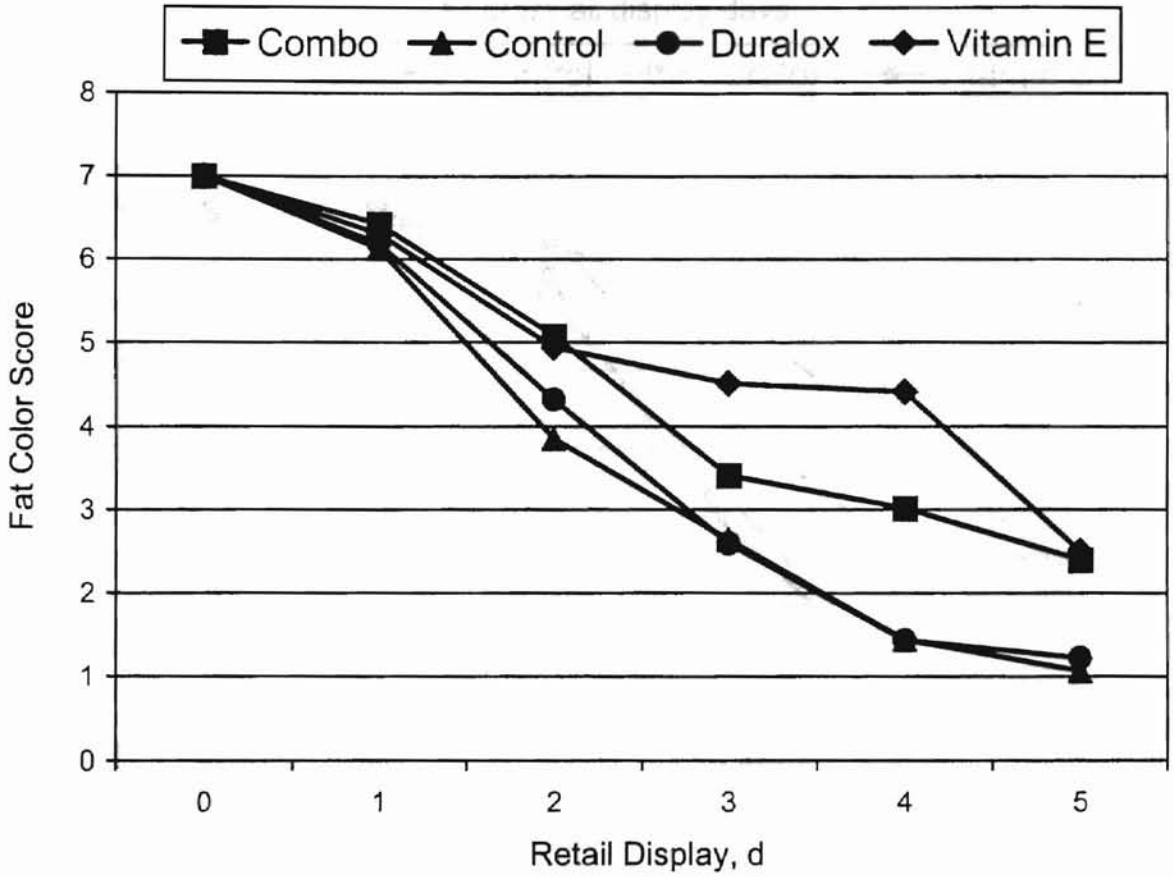


	Treatment[a]			
Day	Control	Duralox	Vitamin E	Combo
0	7.17^{c}	7.11^{c}	6.96^{d}	7.69^{b}
1	6.07^{f}	6.25^{e}	6.15^{ef}	6.90^{d}
2	4.04^{l}	4.63^{m}	5.14^{h}	5.57^{g}
3	2.79^{p}	2.63^{o}	4.83^{l}	3.79^{m}
4	1.17^{rs}	1.14^{rs}	4.28^{k}	2.96^{n}
5	1.06^{s}	1.29^{r}	2.55^{q}	2.48^{q}

[a]SE= RSD*1/√n.

[b-s]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 4.2: Comparison of visual fat color scores of ground beef patties across all display days.

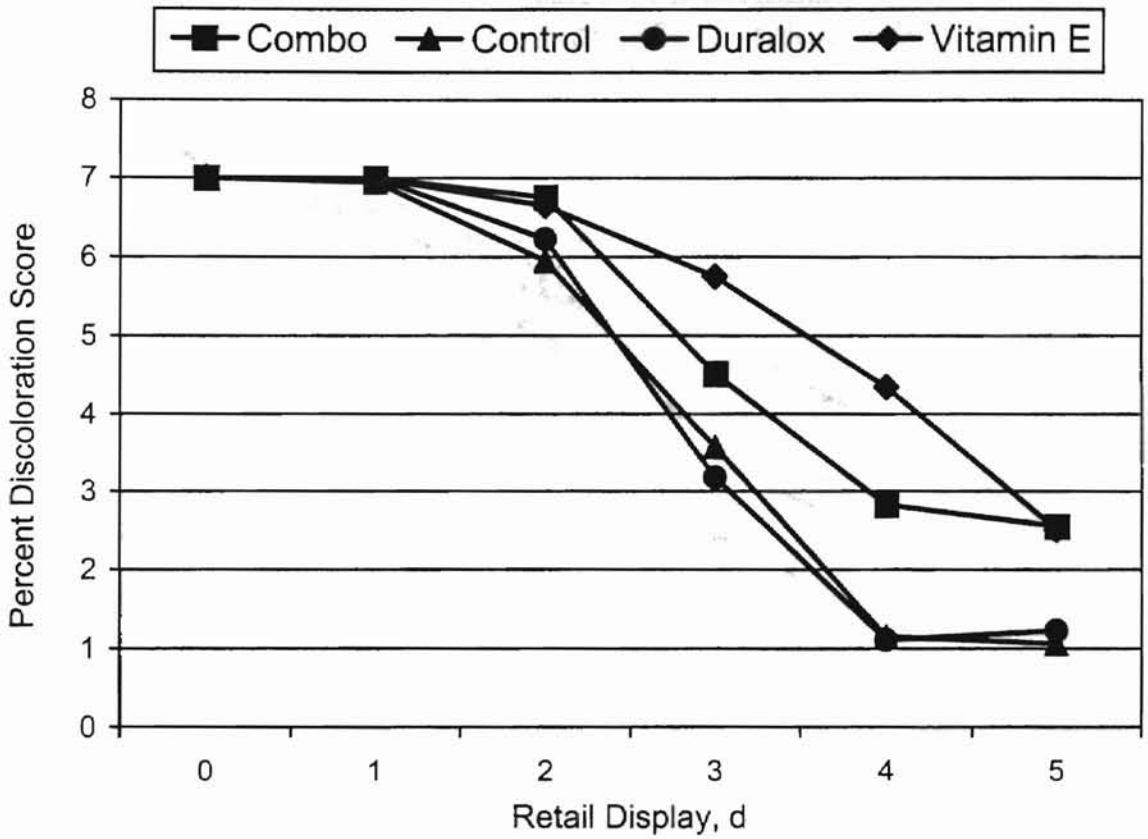


	Treatment[a]			
Day	Control	Duralox	Vitamin E	Combo
0	7.00[b]	7.00[b]	7.00[b]	7.00[b]
1	6.13[e]	6.19[de]	6.31[cd]	6.42[c]
2	3.85[l]	4.32[h]	4.94[f]	5.08[f]
3	2.64[l]	2.59[l]	4.51[g]	3.41[m]
4	1.44[n]	1.43[n]	4.41[gh]	3.01[k]
5	1.06[p]	1.22[o]	2.50[lm]	2.40[m]

[a]SE= RSD*1/√n.

[b-p]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 4.3: Comparison of visual percent discoloration scores for ground beef patties across all display days.

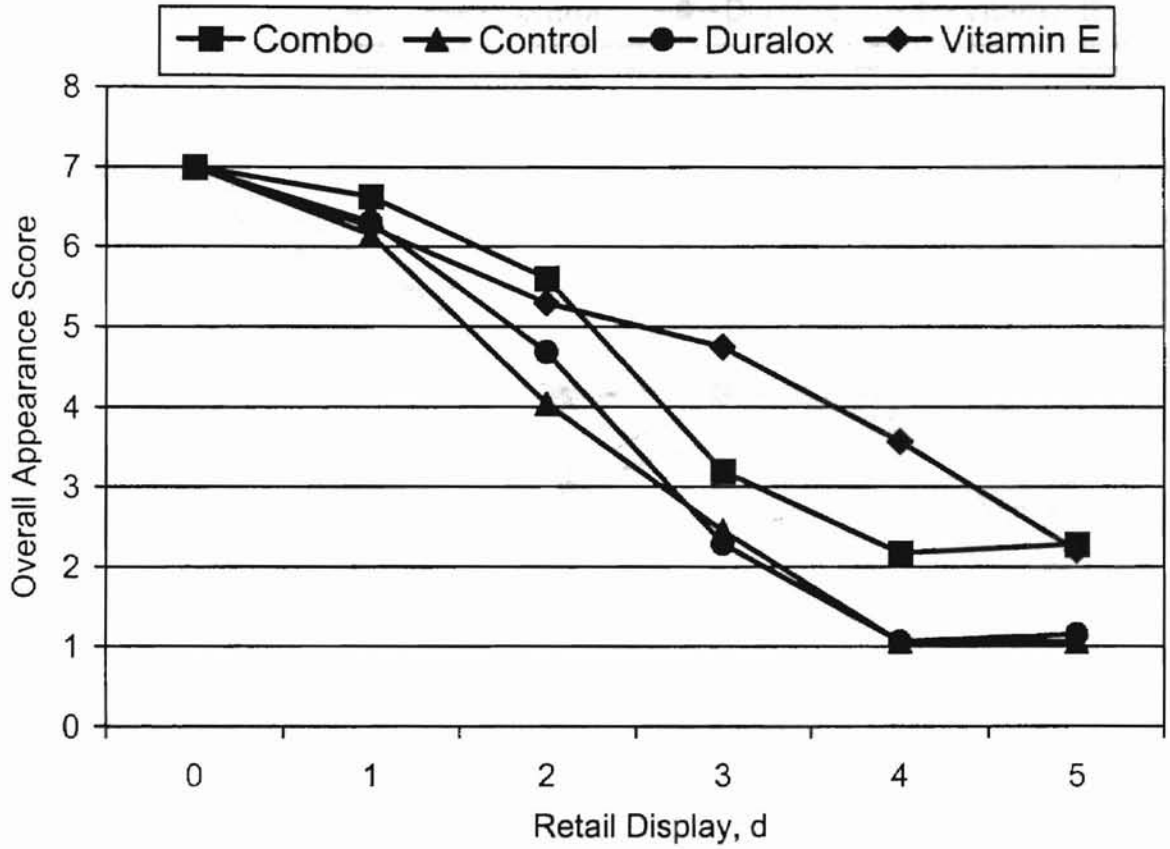


	Treatment[a]			
Day	Control	Duralox	Vitamin E	Combo
0	7.00^{b}	7.00^{b}	7.00^{b}	7.00^{b}
1	6.95^{b}	7.00^{b}	6.99^{b}	7.00^{b}
2	5.95^{e}	6.22^{d}	6.65^{c}	6.76^{c}
3	3.57^{h}	3.18^{i}	5.75^{f}	4.51^{g}
4	1.15^{l}	1.11^{m}	4.34^{g}	2.83^{m}
5	1.06^{n}	1.23^{l}	2.51^{k}	2.55^{k}

[a]SE= RSD*1/√n.

[b-n]Numbers with differing superscripts within the same row are significantly different (P <.05).

Figure 4.4: Comparison of overall appearance scores of ground beef patties across all display days.

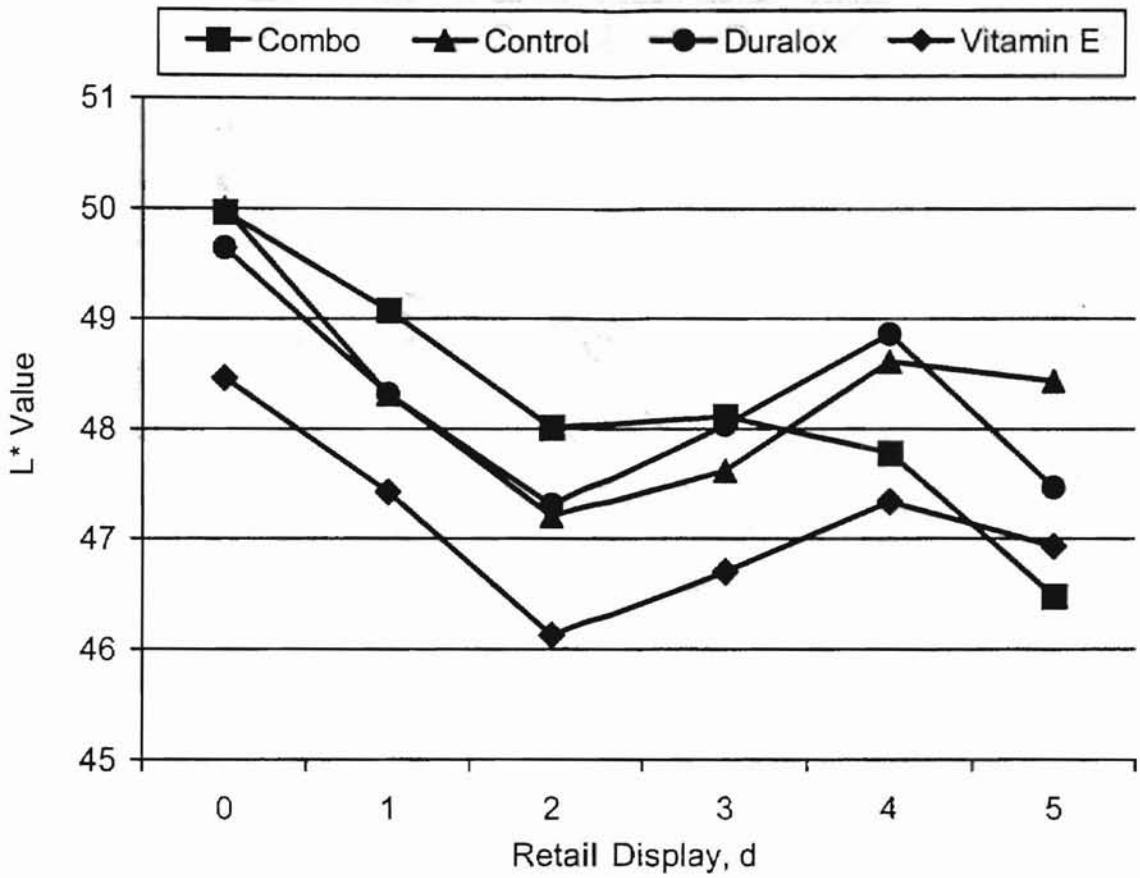


	Treatment[a]			
Day	Control	Duralox	Vitamin E	Combo
0	7.00[b]	6.99[b]	6.99[b]	7.00[b]
1	6.15[e]	6.31[d]	6.25[d]	6.63[c]
2	4.04[l]	4.68[h]	5.29[g]	5.60[f]
3	2.44[l]	2.28[m]	4.74[h]	3.20[k]
4	1.06[n]	1.06[n]	3.56[m]	2.17[m]
5	1.06[n]	1.14[n]	2.20[m]	2.28[m]

[a]SE= RSD*1/√n.

[b-n]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 4.5: Comparison of Minolta L* values of ground beef patties across all display days.

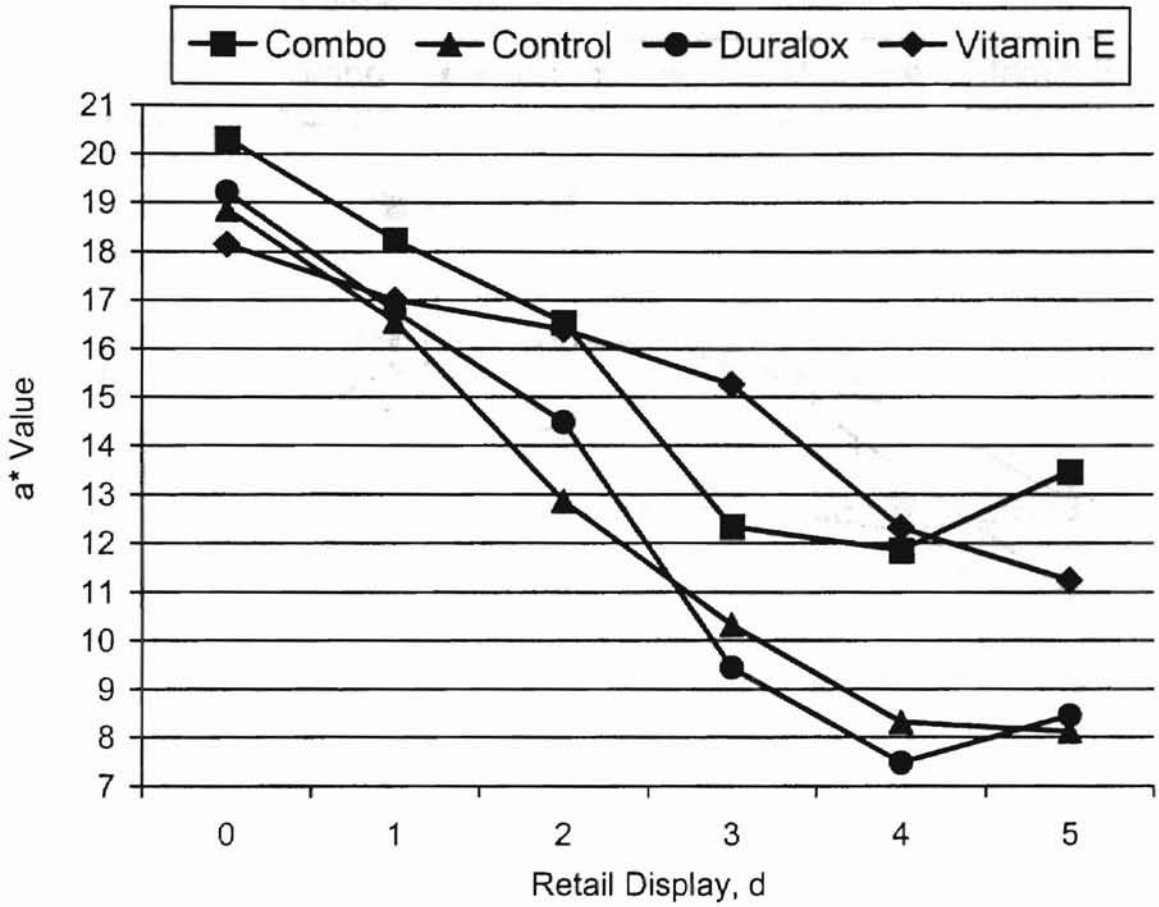


	Treatment[a]			
Day	Control	Duralox	Vitamin E	Combo
0	50.00^{b}	49.64^{bc}	48.46^{efgh}	49.97^{b}
1	48.31^{fgh}	48.31^{fgh}	47.42^{klm}	49.08^{cde}
2	47.20^{lmn}	47.30^{lmn}	46.12^{o}	48.01^{ghijk}
3	47.62^{ijkl}	48.03^{ghik}	46.70^{no}	48.11^{ghi}
4	48.61^{efg}	48.86^{def}	47.33^{lm}	47.78^{hijkl}
5	48.43^{fgh}	47.46^{jklm}	46.93^{mn}	46.48^{no}

[a]SE= RSD*1/√n.

[b-o]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 4.6: Comparison of Minolta a* values for ground beef patties across all display days.

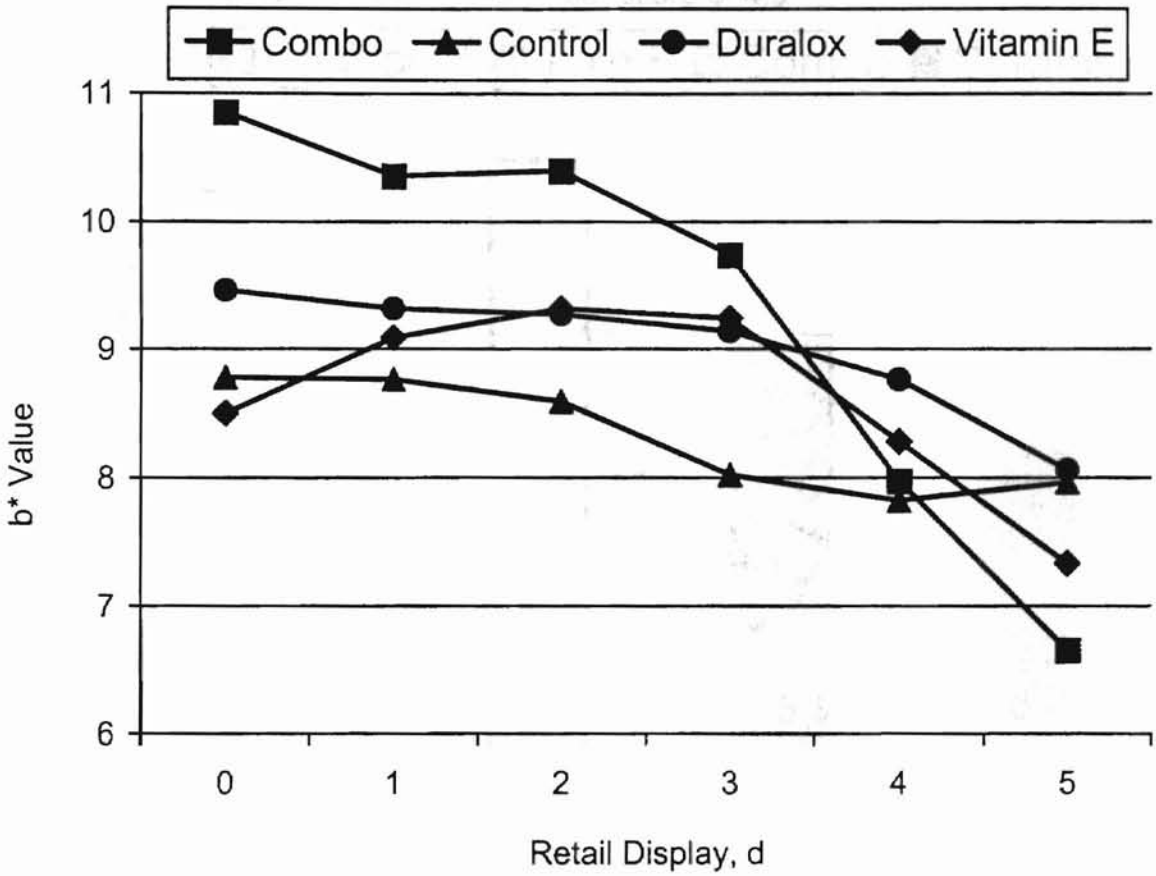


	Treatment[a]			
Day	Control	Duralox	Vitamin E	Combo
0	18.85^{c}	19.22^{c}	18.14^{d}	20.31^{b}
1	16.56^{f}	16.77^{ef}	17.00^{e}	18.24^{d}
2	12.86^{m}	14.48^{h}	16.40^{f}	16.55^{f}
3	10.33^{n}	9.44^{o}	15.26^{g}	12.34^{k}
4	8.32^{p}	7.47^{q}	12.31^{k}	11.86^{l}
5	8.11^{p}	8.45^{p}	11.24^{m}	13.47^{i}

[a]SE= RSD*1/√n.

[b-p]Numbers with differing superscripts within the same row are significantly different (P < .05).

Figure 4.7: Comparison of Minolta b* values of ground beef patties across all display days.



	Treatment[a]			
Day	Control	Duralox	Vitamin E	Combo
0	8.78^{gh}	9.46^{de}	8.50^{hi}	10.85^{b}
1	8.76^{h}	9.32^{ef}	9.09^{fg}	10.36^{c}
2	8.59^{h}	9.27^{ef}	9.32^{ef}	10.40^{c}
3	8.02^{jk}	9.14^{ef}	9.24^{ef}	9.74^{d}
4	7.82^{k}	8.76^{h}	8.28^{ij}	7.97^{k}
5	7.96^{k}	8.06^{jk}	7.33^{l}	6.65^{m}

[a]SE= RSD*1/√n.

[b-m]Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Figure 4.8: Comparison of the number of days required for each treatment group to reach a lean color score of 4.5

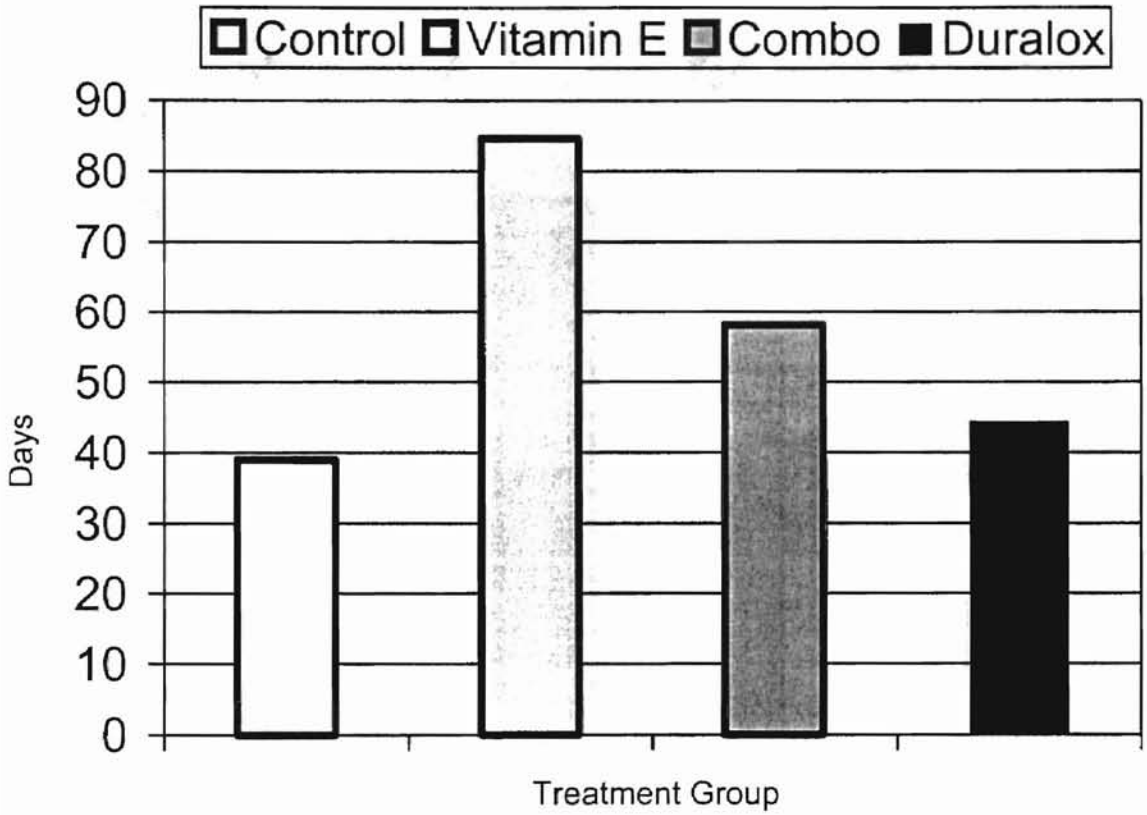


Figure 4.9: Comparison of the number of days required for each treatment group to reach an overall acceptability score of 4.5

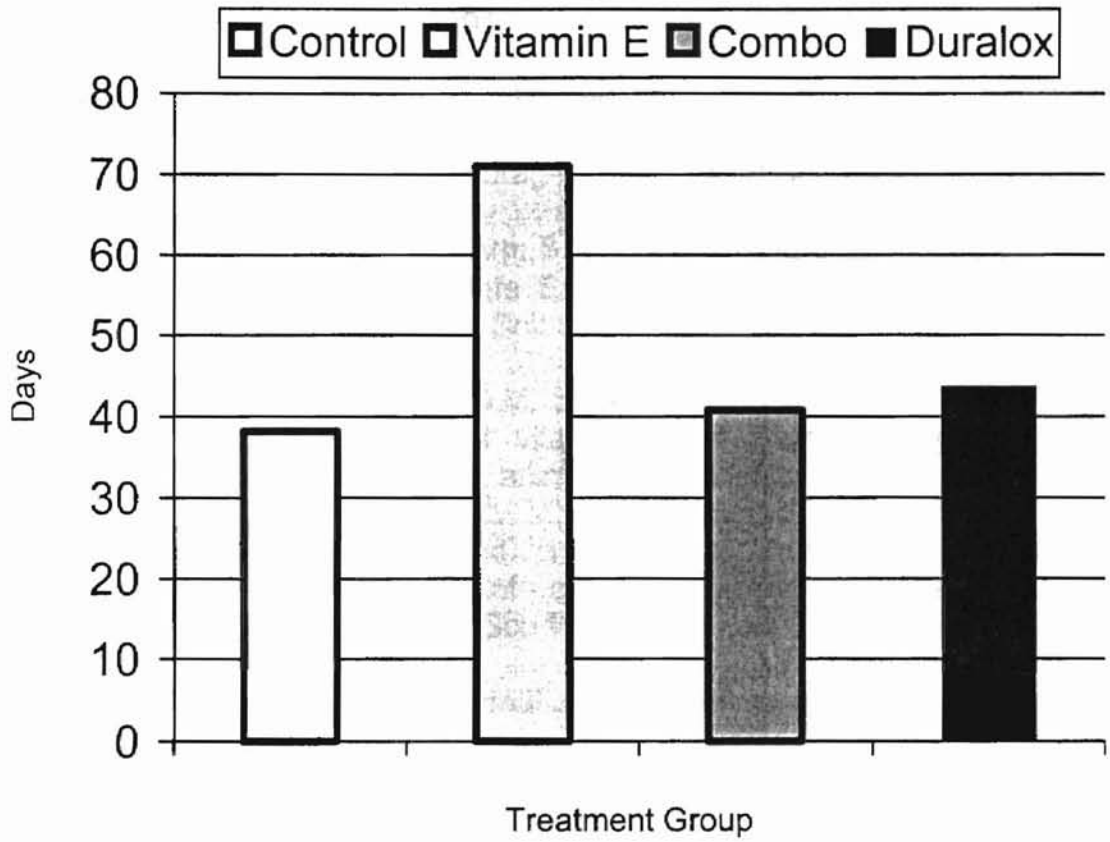


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Table 7: Least Squares Means for visual panel color analysis for each treatment group across all display days.

	Treatment				
Attribute	Control	Vitamin E	Duralox	Herbalox	SEM
Lean Color	4.47[a]	5.68[b]	5.24[c]	5.11[d]	.03
Fat Color	4.47[a]	5.68[b]	5.24[c]	5.11[c]	.12
Percent Discoloration	4.65[a]	5.50[b]	5.15[c]	5.00[d]	.29
Overall Appearance	4.29[a]	5.22[b]	4.87[c]	4.78[d]	.03

Numbers with differing superscripts within the same row are significantly different ($P<.05$).

Table 8: Least Squares Means for L*, a* and b* color analysis for each treatment group across all display days.

	Treatment				
Attribute	Control	Vitamin E	Duralox	Herbalox	SEM
L*	47.28^{a}	50.38^{b}	49.57^{c}	49.33^{c}	.16
a*	13.32^{a}	15.00^{b}	14.22^{bc}	14.11^{ac}	.28
b*	6.51^{a}	7.81^{b}	7.45^{c}	7.87^{b}	.09

Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Table 9: Least Squares Means for TBARS values for each treatment group across all display days.

Treatment	Mean TBA value	SEM
Control	1.18^{a}	.18
Vitamin E	$.27^{b}$	.18
Duralox	$.18^{b}$	.18
Herbalox	$.16^{b}$	.18

Numbers within the same column with differing superscripts are significantly different ($P<.05$)

Table 10: Least Squares Means for visual panel color analysis of ground beef patties for each treatment group across all display days.

	Treatment				
Attribute	Combo	Control	Duralox	Vitamin E	SEM
Lean Color	4.90^{a}	3.72^{b}	3.84^{b}	4.98^{a}	.25
Fat Color	4.58^{a}	3.64^{b}	3.75^{c}	5.01^{d}	.03
Percent Discoloration	5.11^{a}	4.28^{b}	4.29^{b}	5.54^{a}	.27
Overall Appearance	4.48^{a}	3.63^{b}	3.74^{b}	4.84^{a}	.23

Numbers with differing superscripts within the same row are significantly different ($P<.05$).

Table 11: Least Squares Means for L*, a* and b* color analysis of ground beef patties for each treatment group across all display days.

	Treatment				
Attribute	Combo	Control	Duralox	Vitamin E	SEM
L*	48.24[a]	48.36[a]	48.27[a]	47.16[b]	.21
a*	15.46[a]	12.51[b]	12.64[b]	15.06[a]	.54
b*	9.33[a]	8.32[b]	9.00[ac]	8.63[bc]	.09

Numbers with differing superscripts within the same row are significantly different ($P < .05$).

Table 12: Least Squares Means for TBARS values of ground beef patties for each treatment across all display days

Treatment	Mean TBARS Values	SEM
Control	.46[b]	.03
Vitamin E	.19[a]	.03
Combo	.11[a]	.03
Duralox	.11[a]	.03

Numbers with differing superscripts within columns are significantly different ($P < .05$)

VITA[2]

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